FINAL REPORT

CENTERLINE PAVEMENT MARKINGS ON TWO-LANE MOUNTAIN HIGHWAYS

Volume II

Statistical Analysis of Field Data and Kinematic Pass Model

by

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and

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The Virginia Department of Highways and Transportation uses a special 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 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. The Research Council undertook a study to evaluate this centerline marking pattern, and the results are presented here. The methodology adopted included a before and after study. The before study entailed a literature review, a questionnaire survey of motorists and officials of other states, the photographing of passing maneuvers at different sites, 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, based on the speed of the passing vehicle and the speed difference between the passing and impeding vehicles. The after study entailed the collection 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 did not significantly change when centerline markings were changed from MPM to the standard MUTCD and that the minimum length of passing zones and minimum 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 guidelines developed in the study for minimum requirements of passing zones and sight distances were adequate for passing maneuvers on two-lane highways in mountainous areas.

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INTRODUCTION

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. This special marking, designated "mountain pavement marking (MPM)," consists of a single, broken yellow line supplemented with "PASS WITH CAUTION" signs. 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 judgement of the motorist. The argument in favor of this marking pattern is that motorists can legally pass slow moving vehicles, which will not be possible for long distances if these roads are marked in compliance with the MUTCD standards, because of their circuitous alignment.

This practice of marking two-lane highways in mountainous areas has been criticized by the Federal Highway Administration, highway safety officials, and motorists. In keeping with the national emphasis on providing uniform road markings 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.

The final report of this study consists of two volumes. This volume presents --

1. a detailed statistical analysis of the collected data,

2. an analysis of headway distributions in queues, and

3. a step-by-step development of the kinematic pass model.

Volume I of the report contains the summary of findings and consists of --

1. the methodology used in carrying out the study,

2. results obtained from analysis of data collected during the before and after phases of the study,

3. a description of the models developed for minimum passing sight distances and minimum lengths of passing zones in mountainous areas,

4. recommended guidelines for establishing passing and no-passing zones on two-lane highways located in mountainous areas, and

5. the expected consequences of implementing the recommendations on mountainous roads in the Commonwealth of Virginia.

DESCRIPTION OF STUDY SITES

The criteria used in selecting the study sites are given in Volume 1. The locations are given in Table 1 and their general characteristics in Table 2.

Site S-1 on Route 501 has a sag-shaped vertical alignment that differentiates it from the rest of the sites. The curvatures of the approaches of the site are flatter than those for the other sites, except those on site S-2 on Route 311. Also, site S-1 has a relatively long sight distance, which permits motorists to drive at a higher operational speed.

Site S-2 has a very steep grade; however, it is provided with flat horizontal curvatures on both approaches. At this site most of the passes are started on the steepest portion on the upgrade at the entrance of the site and are completed after a low crest caused by the succeeding flatter grade, which is located approximately in the middle of the site.

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

Site S-5 on Route 116 has a moderate available sight distance, steep grade, and sharp curves on both approaches.

TABLE 1

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 2

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.

TRAFFIC OPERATING CHARACTERISTICS

Using the reduced data, standard statistical analyses were performed on traffic operating characteristics. In this section, the results of the statistical analyses are presented. The analyses were undertaken under the following categories in order to develop criteria for passing zones and passing sight distance requirements.

- o Peak-hour volumes at the study sites
- o Speed distribution (mean, 85th and 15th percentile speeds)
- o Speed difference between the opposing lanes
- o Speeds of passing and impeding vehicles
- o Speed of passing vehicle and 85th percentile operating speed

Peak-Hour Characteristics at Study Sites

Table 3 shows the average traffic volumes for selected time periods. It indicates that sites S-1, S-3, and S-4 do not have distinct peak-hour volumes, but sites S-2 and S-5 do. At sites S-2 and S-5, the morning peak starts around 6:00 a.m. and lasts until about 8:00 a.m.; the afternoon peak commences about 3:00 p.m. and ends about 6:00 p.m.

Speed Distribution

Percentage and cumulative percentage distributions of operating speeds for the study sites are shown in Figure 1, and the mean, 85th percentile, and 15th percentile speeds are summarized in Table 4.

It should be noted that apart from site S-1, which has a relatively long site distance, the 85th percentile speeds are approximately between 40 and 50 mph and the mean speeds between 35 and 45 mph. The 15th percentile speeds are in the range of 30 and 40 mph. On the average, speed differences between the 85th percentile and 15th percentile speeds are 10 mph.

Speed Difference Between Opposing Lanes

The difference in speed between opposing lanes on two-lane, two-way highways is usually not high enough 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 slope may be large enough to be considered.

TABLE 3

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	
	NB	SB	EB	WB	NB	SB	EB	WB	NB	SB
0600 - 0800	34	45	219	42	21	18	36	25	191	24
0800 - 1000	33	45	99	75	27	25	35	43	72	38
1000 - 1400	35	29	71	71	44	39	38	36	47	44
1400 - 1600	45	40	102	118	42	48	50	48	52	51
1600 - 1800	59	41	86	196	52	51	46	49	55	167

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

All days were clear and dry.

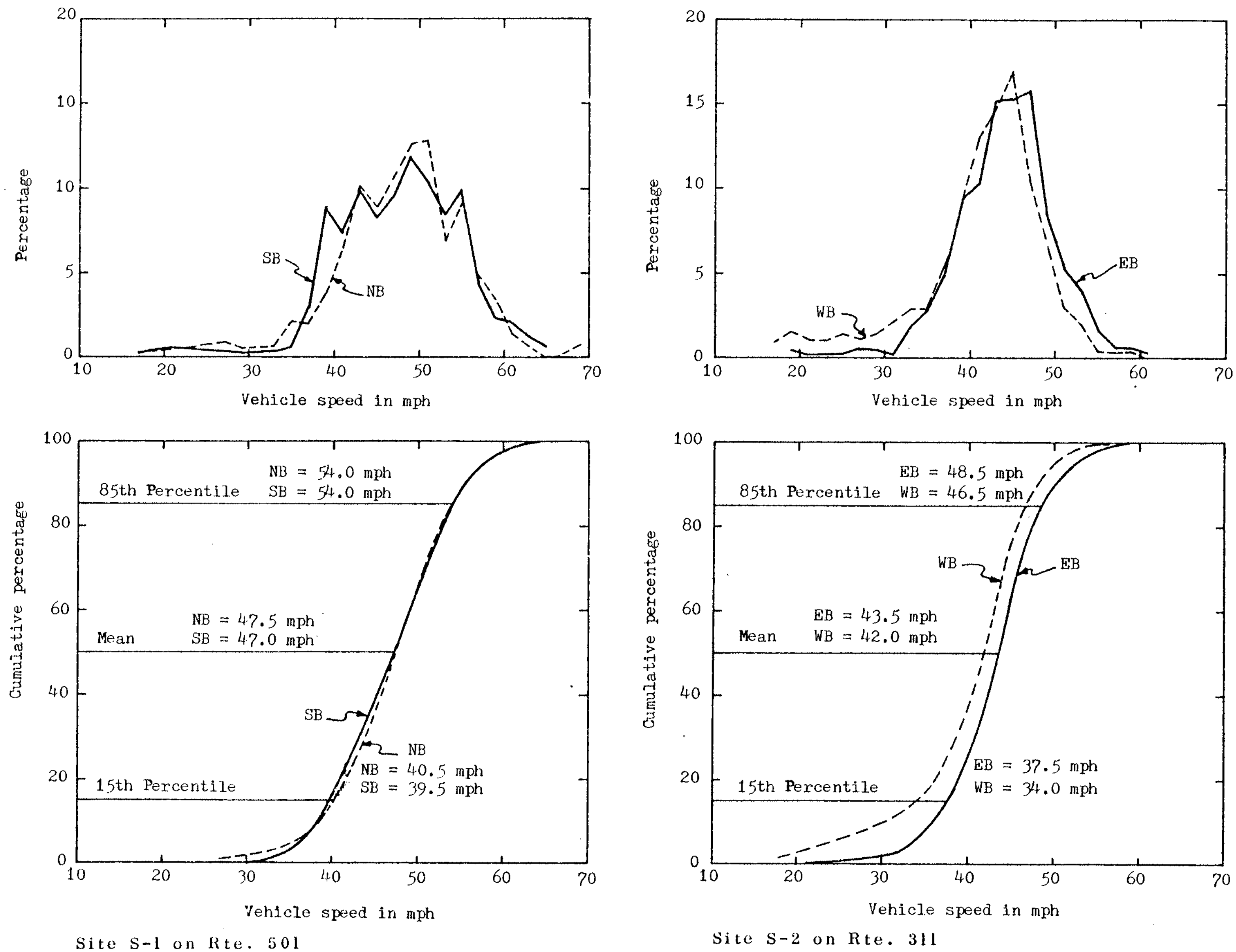
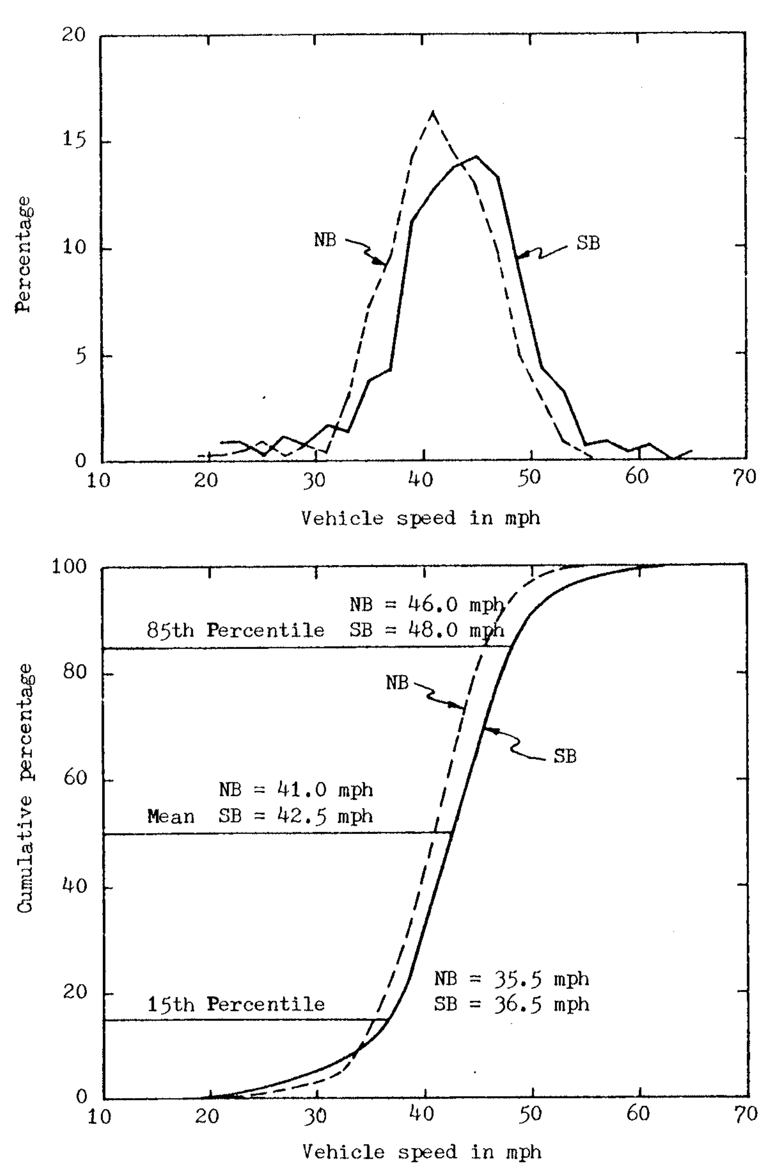
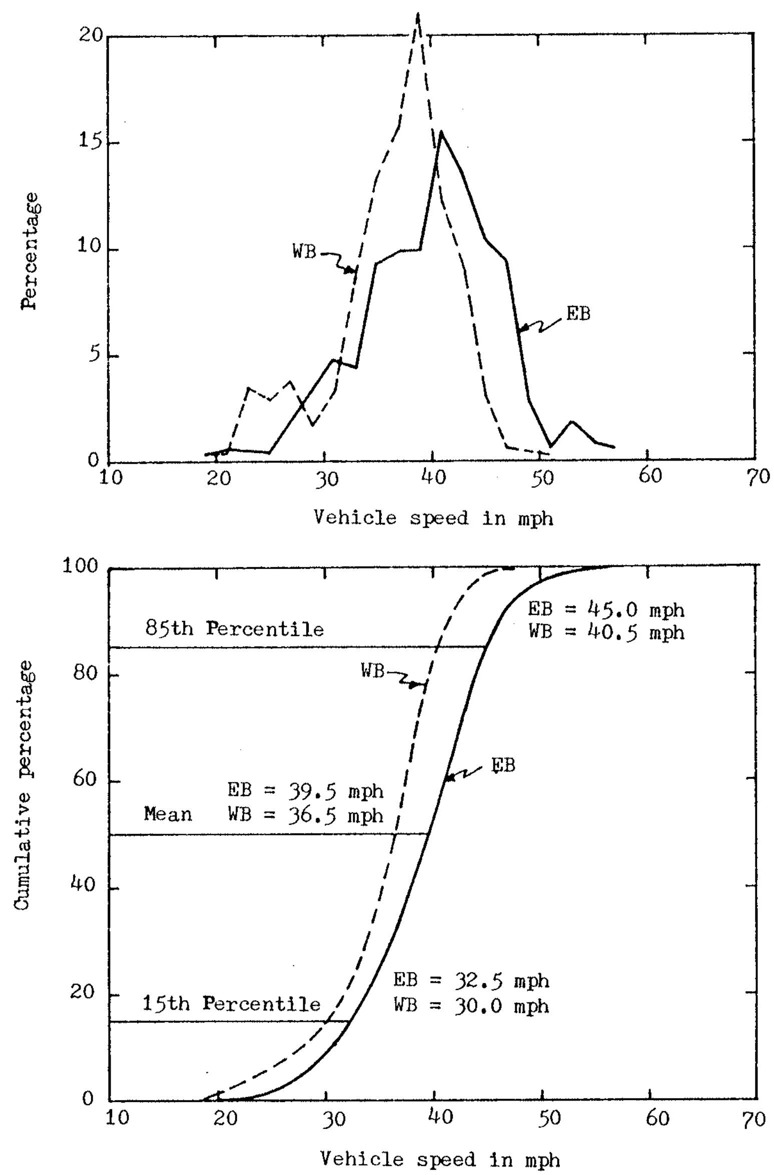


FIGURE 1. SPEED DISTRIBUTION AT STUDY SITES.



Site S-3 on Rte. 220



Site S-4 on Rte. 130

FIGURE 1. CONTINUED.

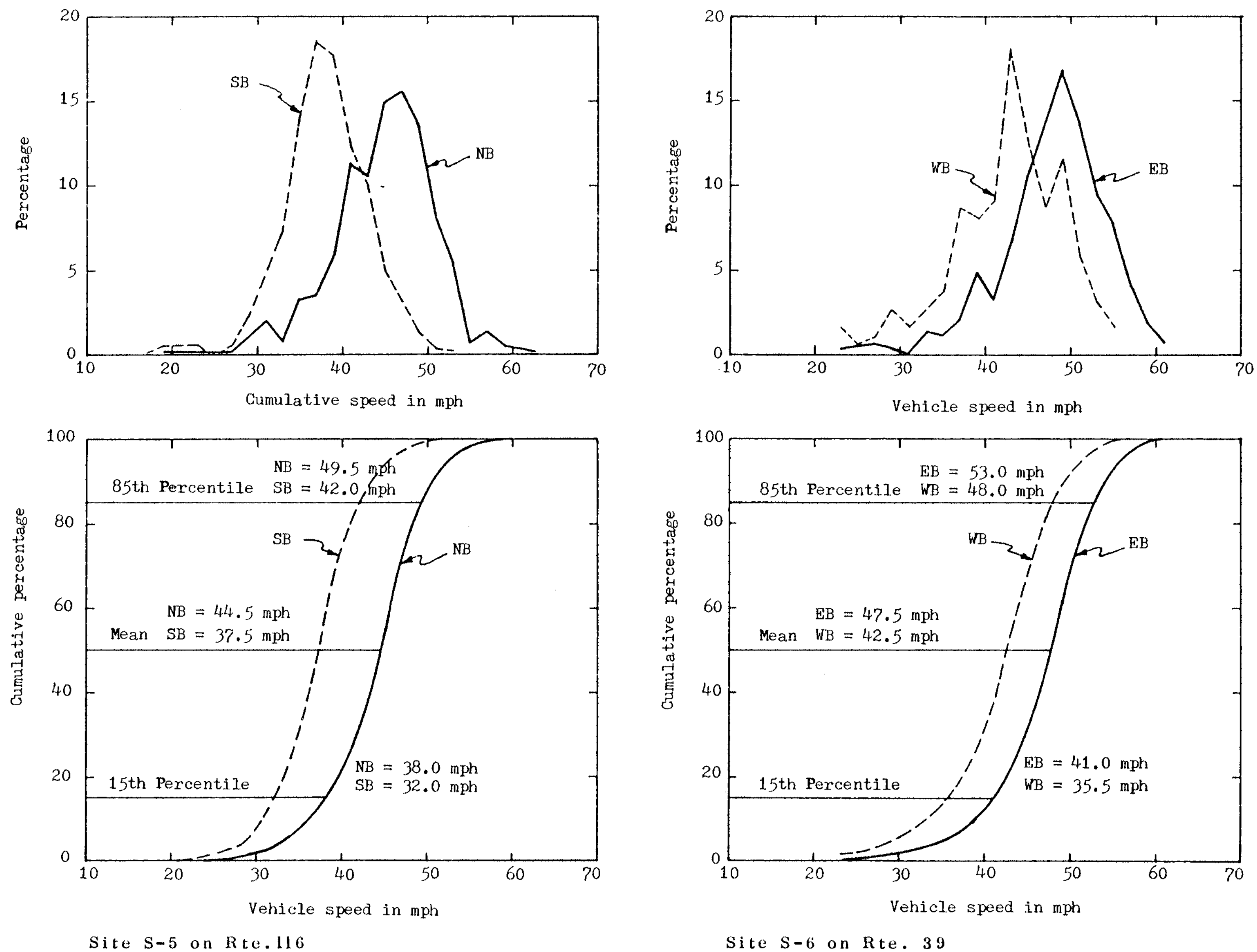


FIGURE 1. CONTINUED.

TABLE 4

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

NOTE: Speeds based on the cumulative percentage curves in Figure 1.

To determine whether there was a significant difference between the speeds on the opposing lanes, the normal approximation test (means test for two independent samples with standard deviation known) was used. The test was carried out for a 95% confidence level. Since the accuracy of speed data provided by the electronic data acquisition system is ± 1.0 mph,(2) the tolerance error could not be less than that. Therefore, the maximum tolerable error was set at ± 1.0 mph to estimate required sample sizes. The estimated sample size and desired sample size are shown in Table 5 along with the results of the means test on the speed difference between the upslope and downslope.

At the 95% confidence level, the speed difference between the upslope and downslope was not significant at sites S-1 and S-4. It is reasonable for the speed difference not to be significant at site S-1 as there is a sag vertical curve at this site. Site S-4 has the least grade (± 4.3%) among the study sites with a continuous slope. At the rest of the study sites -- S-2, S-3 and S-5 -- the speed differences between the opposite lanes were significant. All of these sites have gradients greater than 5%.

Speed of Passing and Impeding Vehicles

The speed data for the passing and impeding vehicles are plotted in Figure 2. Despite the different conditions at the sites, the figure illustrates a good correlation between the speeds of the passing and impeding vehicles. This illustrates that most of the passing motorists determined a similar desired speed to overtake and complete the pass based upon the speed of the impeding vehicle. Also, the least squares regression line indicates that the desired speed difference increased directly with an increase in the speed of the passing vehicle, although the increments were small. The speeds of impeding vehicles varied from 15 to 45 mph, whereas those of the passing vehicles ranged from 30 to 64 mph. These figures indicate that at these sites motorists did not attempt to pass if their desired speed was less than 30 mph.

To investigate the acceptable speed difference between the passing and impeding vehicles on mountainous roads, a cumulative distribution curve was constructed as shown in Figure 3. Since the graphic representation indicates a normal distribution, a χ^2 goodness-of-fit test was performed to confirm the normality of the data. The actual speed difference obtained for the 36 passes recorded are found in Appendix A. The computed χ^2 value (0.21) was smaller than the $\chi^2_{0.05}$ value (3.84), which indicates that it could be reasonably assumed that the distribution of the speed differences was normal at a 5% significance level.

TABLE 5

SPEED DIFFERENCE BETWEEN OPPOSITE LANES

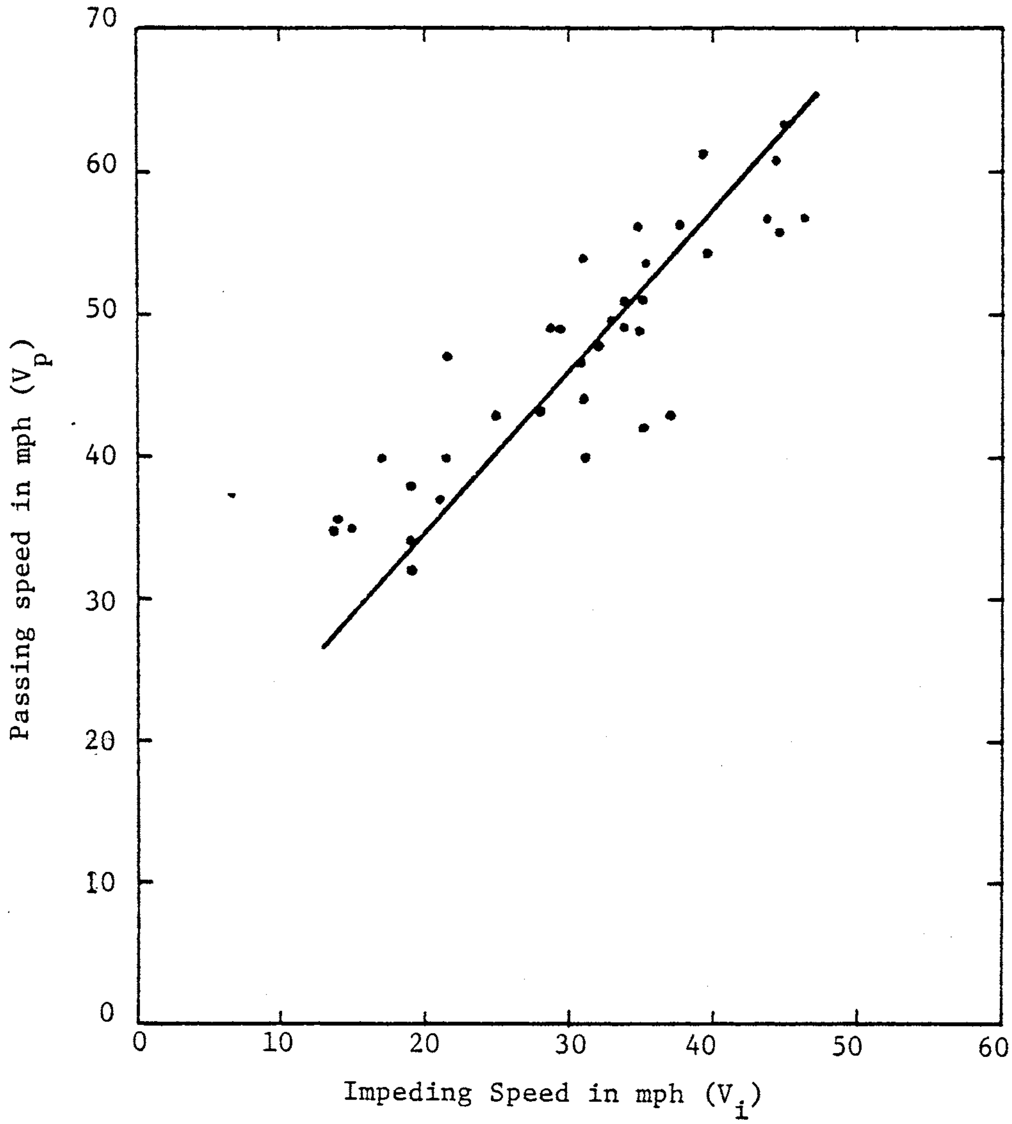
Site No.	Route Number	Direction	Grade (%)	Used[a] Sample Size	Average Speed, mph
S-1	501	Southbound	-3.2 ~ + 6.5	245	46.9
		Northbound	-6.5 ~ + 3.2	245	46.5
S-2	311	Eastbound	-7.8	245	43.9
		Westbound	+7.8	245	40.4
S-3	220	Southbound	-5.4	190	43.4
		Northbound	+5.4	190	41.2
S-4	130	Eastbound	-4.3	190	38.9
		Westbound	+4.3	190	37.8
S-5	116	Southbound	+7.0	220	37.0
		Northbound	-7.0	220	44.3

[a] Samples were taken from the TDR outputs starting at 10:00 a.m.

TABLE 5. CONTINUED

Site No.	Standard Deviation (MPH)	Desired[b] Sample Size for 95.0% CL	F-Value	Z-Score	P-Value	Evaluation
S-1	7.14	196	1.04	0.63	0.529	Not Significant
	7.01	189				
S-2	5.94	135	1.80	5.50	0.000	Significant
	7.98	245				
S-3	5.46	114	1.02	3.91	0.047	Significant
	5.51	116				
S-4	6.45	160	1.10	1.70	0.089	Not Significant
	6.16	145				
S-5	6.29	152	1.10	12.46	0.000	Significant
	6.00	138				

[b]Desired sample size at 95.0% confidence = $(\text{standard deviation})^2/(\text{limit of tolerance error})^2$



Regression line:

$$V_p = 1.13\ V_i + 11.88$$

$r = 0.86$ (Correlation significant at α 0.05)

FIGURE 2. PASSING SPEED VS. IMPEDING SPEED.

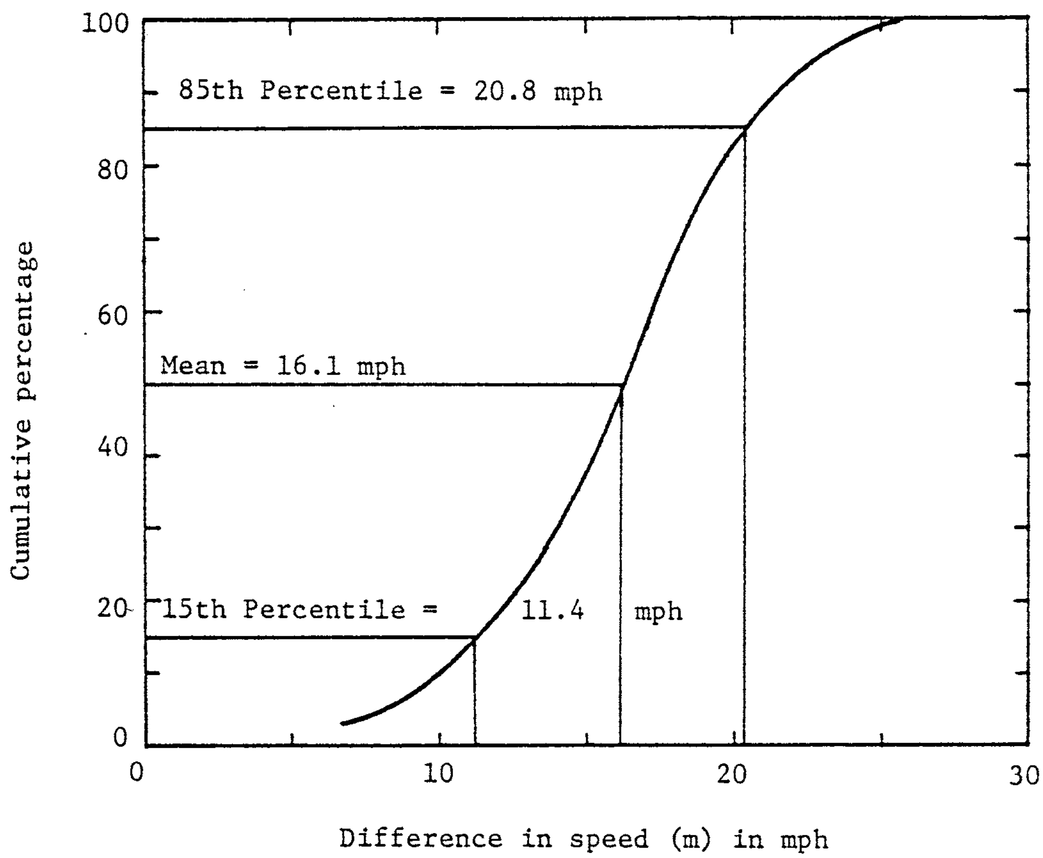


FIGURE 3. CUMULATIVE DISTRIBUTION OF SPEED DIFFERENCE BETWEEN PASSING VEHICLE AND IMPEDING VEHICLE.

Several percentile speed differences were estimated as shown in Table 6. They were computed by the formula

$$m = m + Z \cdot S,$$

where m = speed difference for a particular percentile level.

The difference in speed between impeding vehicle and passing vehicles used by the AASHTO Blue Book is 10 mph.(3) This is close to the 15th percentile speed difference obtained in this study. It should be noted that approximately 55% of the passing vehicles passed the impeding vehicles with a difference in speed of 15 mph or greater. This finding may indicate that the motorists tended to aim at a relatively high desired passing speed on these mountainous roads with limited sight distance in order to complete the pass in the shortest possible distance.

TABLE 6

SPEED DIFFERENCES BETWEEN PASSING AND IMPEDING VEHICLES FOR DIFFERENT PERCENTILE LEVELS

Percentile	Z-Score	Percentile Speed Difference, mph
15th Percentile	- 1.038	11.4
35th Percentile	- 0.386	14.4
45th Percentile	- 0.126	15.5
50th Percentile	0.0	16.1
85th Percentile	+ 1.038	20.8

Passing Speed vs. Off-Peak 85th Percentile Speed

The MUTCD employs the prevailing off-peak 85th percentile speed as a variable to compute the minimum passing sight distance.(4) As shown in Table 7, the off-peak 85th percentile speed was found to be approximately equal to the mean passing speeds. which indicates that it is reasonable to use the prevailing off-peak percentile speed to provide proper minimum passing sight distances.

TABLE 7

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

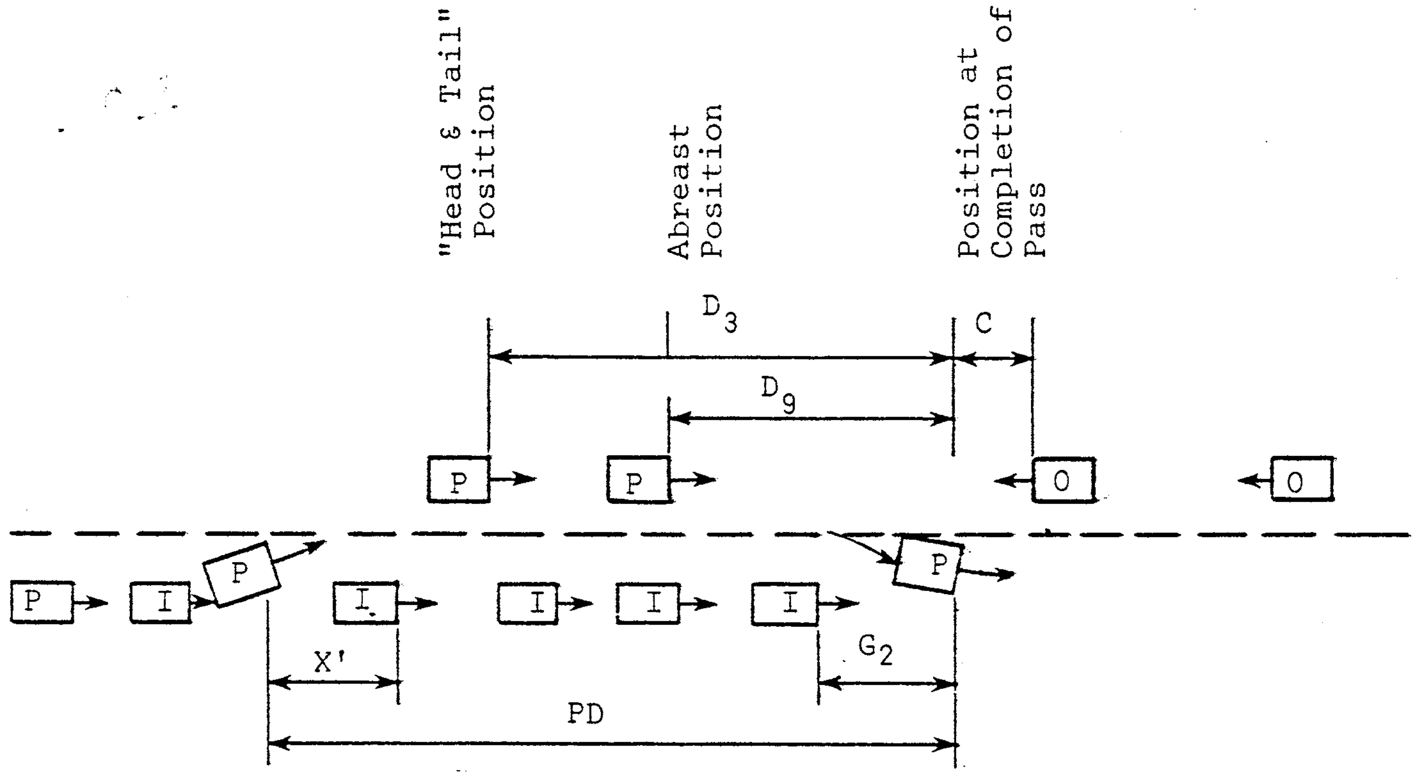
Site No.	Mean Speed of Passing Vehicle, (mph)	Off-Peak 85th Percentile Speed, (mph)
S-1	56.0	54.0
S-2	45.5	46.5
S-3	48.3	46.0
S-4	42.0	40.5
S-5	41.9	42.0

ANALYSIS OF DATA ON PASSING MANEUVER

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 section, the results of the statistical analyses performed upon the distance elements extracted from the films are presented.

Figure 4 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' were extracted from the passes filmed with the 16-mm camera, and the definitions of these elements are shown in the figure. These extracted data are listed in Appendix A along with the type of vehicles involved, speeds of passing and impeding vehicles, speed differences, and the types of passing maneuvers.

In order to reach a general conclusion, however, emphasis was placed more on statistical inferences than on the individual distances extracted from the films. In this section the statistical inferences are discussed.



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 4. DISTANCE ELEMENTS EXTRACTED FROM THE FILMS.

Passing Distance (PD)

PD in this study 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. Generally, PD is described as a function of the passing speed, and in the case of the MUTCD sanctioned guidelines, it is the prevailing off-peak 85th percentile speed.(4) Therefore, the PDs extracted from the films were plotted as a function of the passing speed as shown in Figure 5.

A correlation analysis showed that the correlation coefficient (r) was 0.62 and the correlation between PD and speed was significant at a 5% significance level. However, the standard error of estimate turned out to be 92.4 ft., which would be substantially large for developing guidelines. An analysis of variance was, therefore, conducted to determine the variables that significantly affect PD. The four variables considered were passing speed, available sight distance, speed difference, and grade.

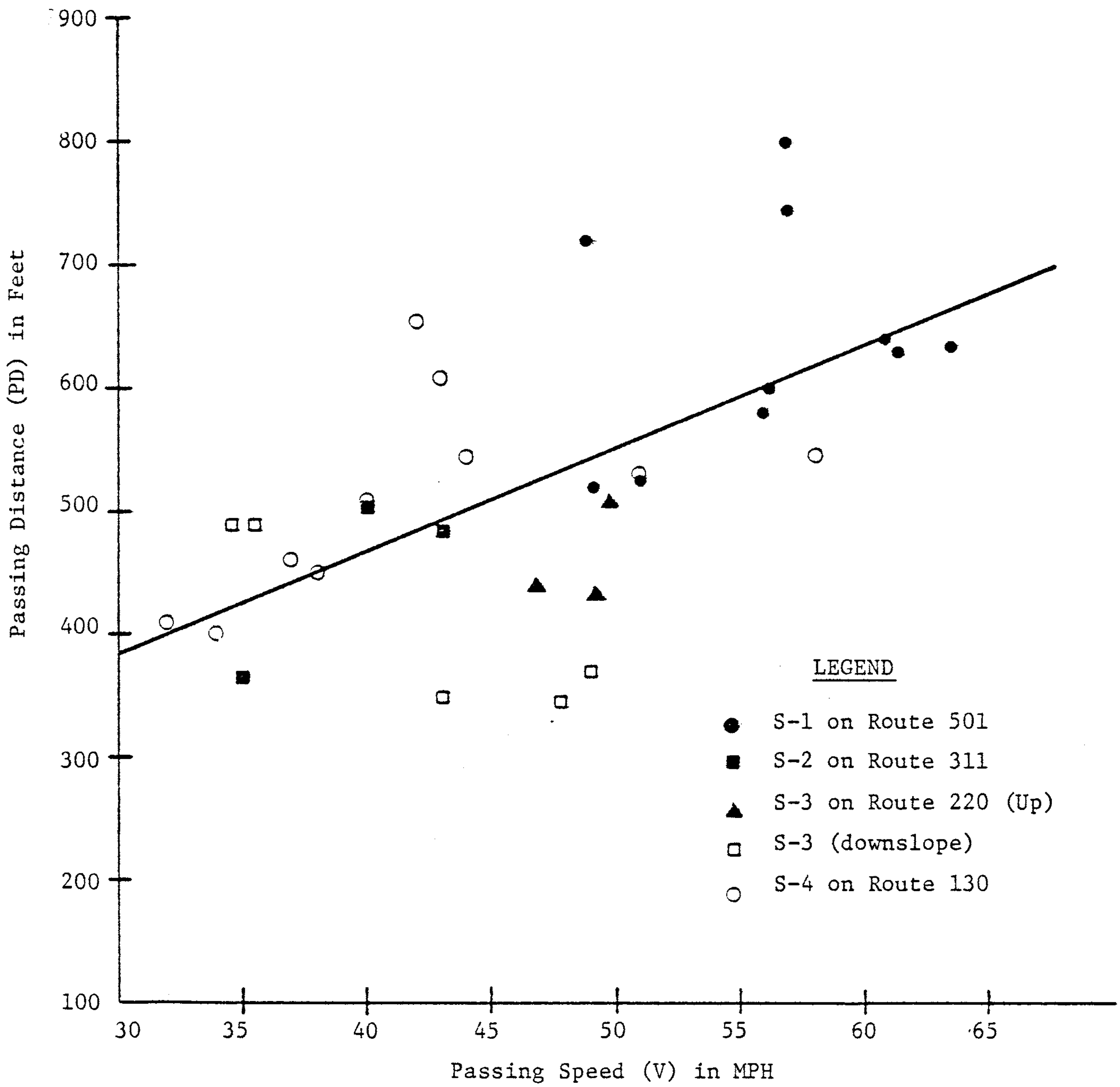
The analysis revealed that these factors had significant effects in the order of the above listing, with grade being the least significant factor. The data used for this analysis are listed in Appendix A. See Appendix B for a summary of the results of the analysis of variance.

Distance Traveled After the Head & Tail Position (D_3)

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. Here, the percentage of D_3 to PD was computed and the result was plotted as shown in Figure 6. A χ^2 goodness-of-fit test was performed in order to examine the normality of the cumulative percentage. It was found that the computed χ^2 value (3.67) was substantially less than the $\chi^2_{0.95}$ value (7.82), which indicated that the data could be assumed to be normally distributed. The mean percentage was 69%, which is close to the two-thirds (0.67) PD described in the AASHTO Blue Book.(3)

Distance Traveled After the Abreast Position (D_9)

D_9 is the distance traveled by the passing vehicle to complete a pass after it has come abreast of the impeding vehicle. Weaver and Woods state that this distance is approximately two-thirds PD(5) based on a study conducted by Weaver and Glennon(6) concerning passing sight distance requirements.



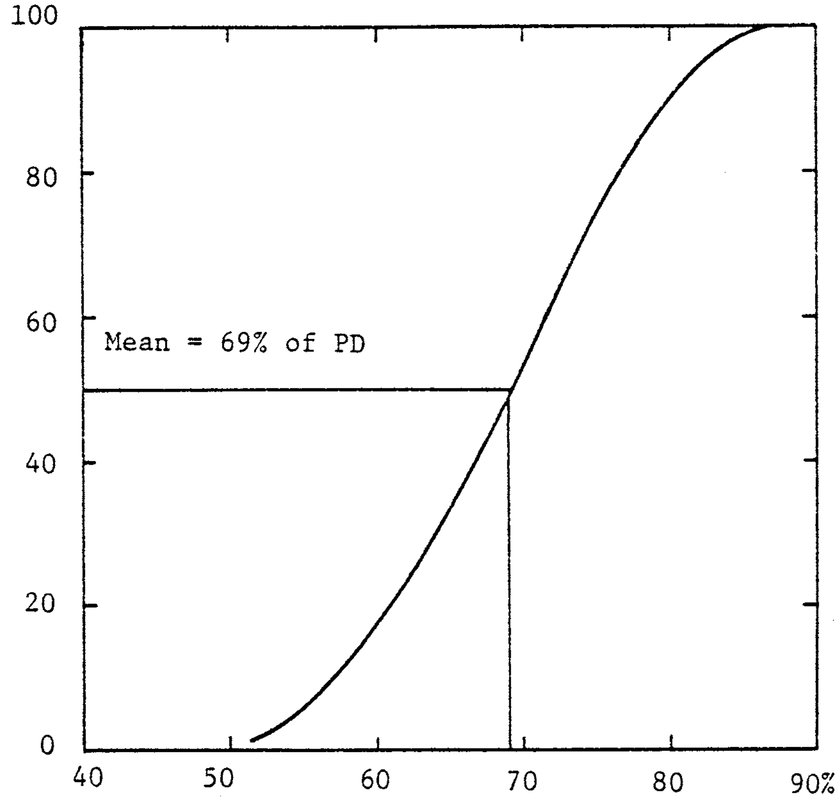
Regression line:

$$PD = 8.34\ V + 134.43$$

$r = 0.62$ (correlation significant at $\alpha = 0.05$)

Standard error of estimate = 92.40 ft.

FIGURE 5. PASSING DISTANCE AS A FUNCTION OF PASSING SPEED.



Percentage of the distance traveled by passing vehicle after it had reached the rear bumper of impeding vehicle to the total passing distance

FIGURE 6. CUMULATIVE PERCENTAGE DISTRIBUTION — D_3 OVER PD IN PERCENT.

To investigate the situation on two-lane, two-way highways in mountainous areas, the percentage of D_9 to PD was computed and the result was plotted as shown in Figure 7. In this study, it was found that the ratio of D_3 to PD was smaller than two-thirds PD.

A χ^2 goodness-of-fit test was performed to investigate the normality of the cumulative percentage distribution. The computed χ^2 value was 1.46, which was considerably lower than the $\chi^2_{0.05}$ value (5.99) and indicated that the data could be assumed to be normally distributed at the 5% significance level. The mean percentage was 56%, which is approximately 10% lower than the value cited by Weaver and Woods.(5) It should be noted that their figure was based on passing maneuvers on two-lane roadways with more favorable geometric conditions than those in mountainous areas.

After Spacing (G_2)

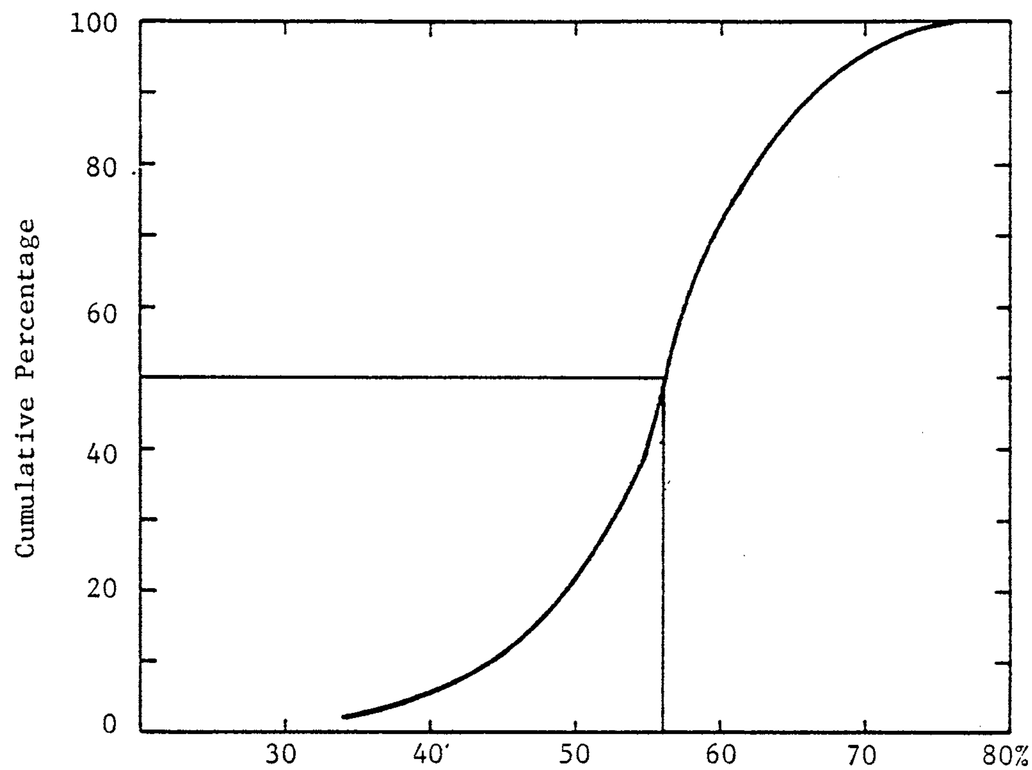
G_2 is the space headway maintained by the passing vehicle over the impeding vehicle (now traveling behind) when it completes the pass. The after spacing data were plotted as a function of the passing speed as shown in Figure 8. A linear regression analysis was performed and the result is also shown in the figure. The correlation coefficient (r) was 0.50 and the correlation between the after spacing G_2 and the passing speed was found to be statistically significant at a 5% significance level.

This regression analysis led to another important finding. In the figure, the gap-speed relation was plotted based on the rule of thumb for the gap between two consecutive vehicles, which is defined as the distance between the rear bumper of the leading vehicle and the front bumper of the following. It is computed as

$$\text{Gap in feet} = (20 \text{ ft.}) \times (\text{velocity in mph})/10.$$

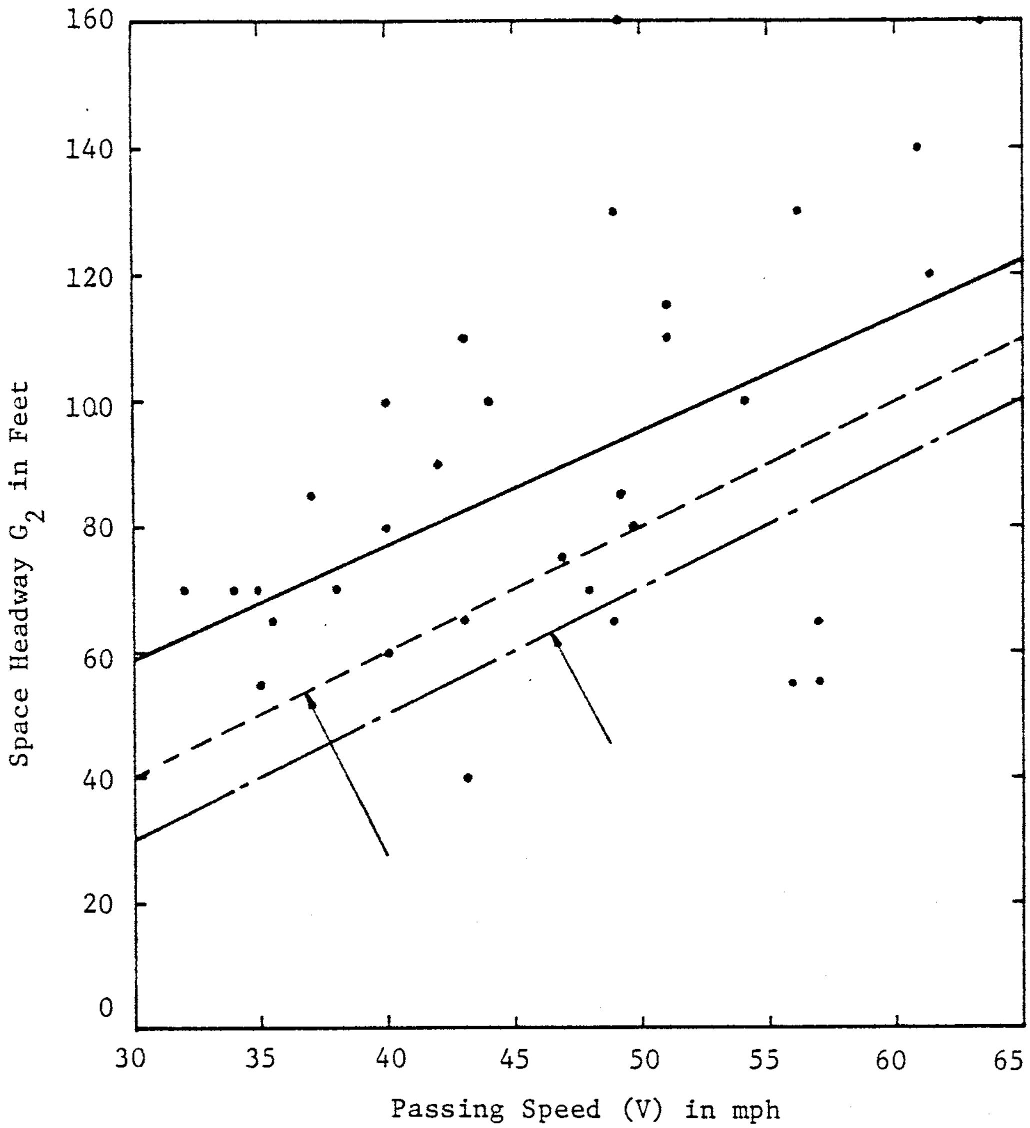
The speed of the impeding vehicle was used in this case since it is the one most affected, in terms of driving safety, by the length of the gap. The relations for two levels of speed difference are shown in Figure 8, along with the regression line between G_2 and the passing speed. This comparison indicates that G_2 is approximately equal to a gap which can be estimated by the rule of thumb plus 20 to 30 ft. Since most of the passing vehicles were passenger cars, as shown in Appendix A, this distance of 20 to 30 ft. reasonably represents the length of the passing vehicles.

In other words, it can be said that the use of the rule of thumb to compute the gap between the preceding vehicle and the following vehicle reasonably reflects the actual maneuver. This finding was later used in developing the kinematic pass model.



Percentage of the distance traveled by passing vehicle after it became abreast of the impeding vehicle to the total passing distance

FIGURE 7. CUMULATIVE PERCENTAGE DISTRIBUTION — Dg OVER PD IN PERCENT.



Regression line:

$$G_2 = 1.80\ V + 4.96$$

$r = 0.50$ (correlation significant at $\alpha = 0.05$)

FIGURE 8. SPACE HEADWAY G_2 AS A FUNCTION OF PASSING SPEED.

Before Spacing (X')

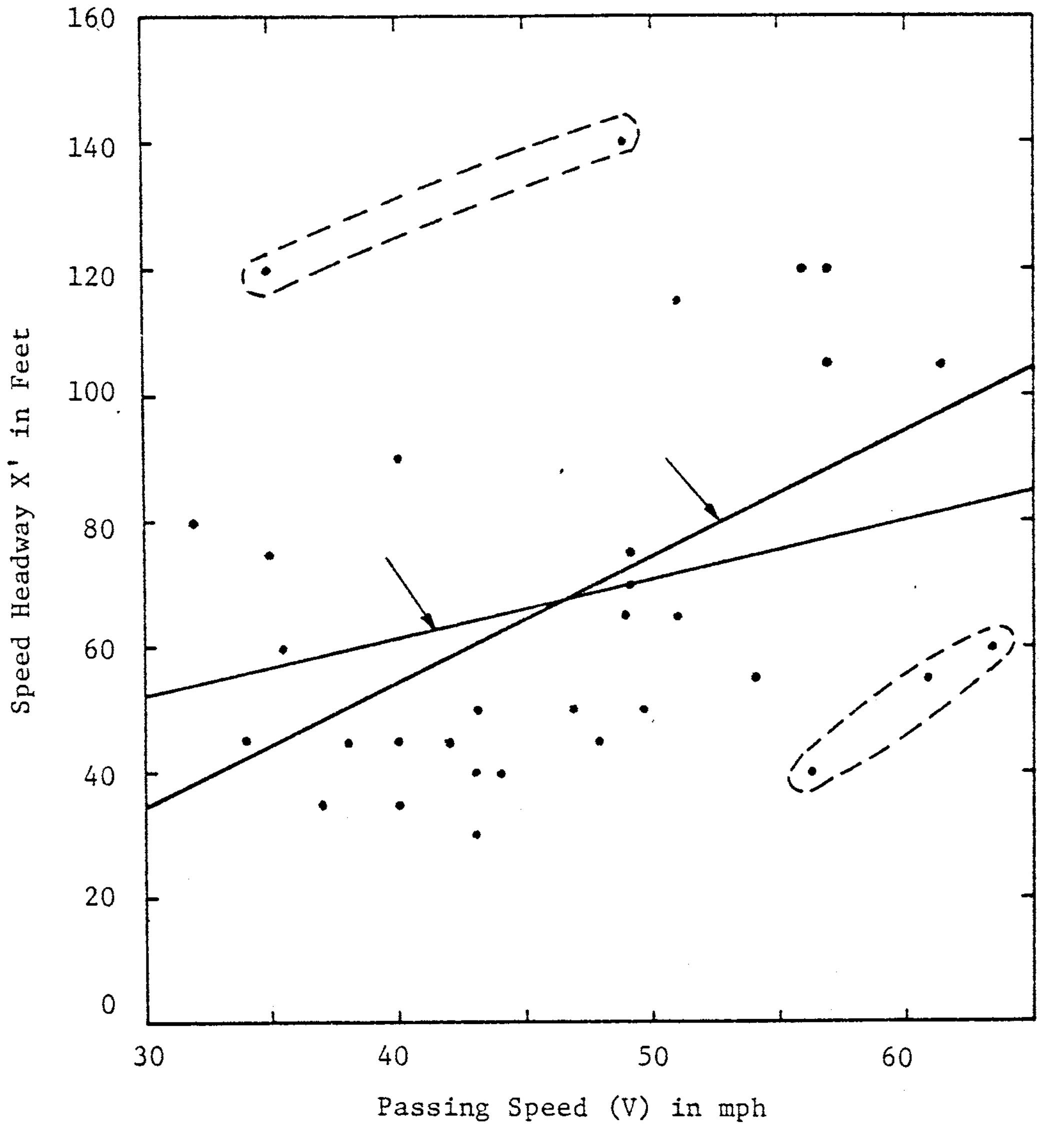
X' is the space headway that the passing vehicle retains just before it encroaches onto the left lane. The data on X' were plotted as a function of the passing speed as shown in Figure 9. The regression line, A, is the result of a regression analysis for all the samples taken on the upslope. The correlation coefficient (r) was 0.27, and the correlation between X' and the passing speed was not significant at a 5% significance level. However, as shown in Figure 9, the samples in the two dotted circles were extreme cases and were excluded. The correlation coefficient for the rest of the data became 0.57 and the correlation was significant at a 5% significance level. The regression line for the second analysis is shown as the regression line B in Figure 9.

This result led to a noteworthy finding. In comparing the regression lines for the space headway G_2 and X' as shown below,

$$G_2 = 1.80\ V + 4.96$$

$$X' = 1.99\ V - 25.30$$

The coefficients for the passing speeds were found to be very close, which suggests that both regression lines behave similarly with respect to variations in the passing speed. Therefore, the ratios of the space headways (F_1), i.e., X' to G_2, were computed for several levels of passing speed as shown in Table 8. Although F_1 became greater with an increase in speed, its average was approximately 0.70. Prisks's study reported that X' was approximately 0.65 of G_2.(7) Prisk reported that the average before spacing was 54 ft. as compared with an 83 ft. after spacing.(7) In this study on mountainous highways, an average of 56 ft. was obtained for the before spacing compared with an average of 79 ft. for the after spacing. Therefore it can be said that as far as these elements are concerned, motorists' perception of the safe spacing during the passing maneuver has not changed substantially since Prisk's early study, despite the improvements made in the capabilities of vehicles.



Regression lines:

A. $X' = 0.94\ V + 23.78$

$r = 0.27$ (correlation not significant at $\alpha = 0.05$)

B. $X' = 1.99\ V - 25.30$

$r = 0.57$ (correlation significant at $\alpha = 0.05$)

Samples in the dotted circles were excluded.

FIGURE 9. SPACE HEADWAY X' AS A FUNCTION OF PASSING SPEED.

TABLE 8

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

Speed of Passing Vehicle (mph)	$X' = F_1 G_2$ (ft.)	G_2 (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 $F_1 = 0.71$

NOTE: X' is the space headway that the passing vehicle maintained when it encroached onto the left lane. The regression line B in Figure 5-6 was used.

G_2 is the space headway left for the impeding vehicle when it completes the pass.

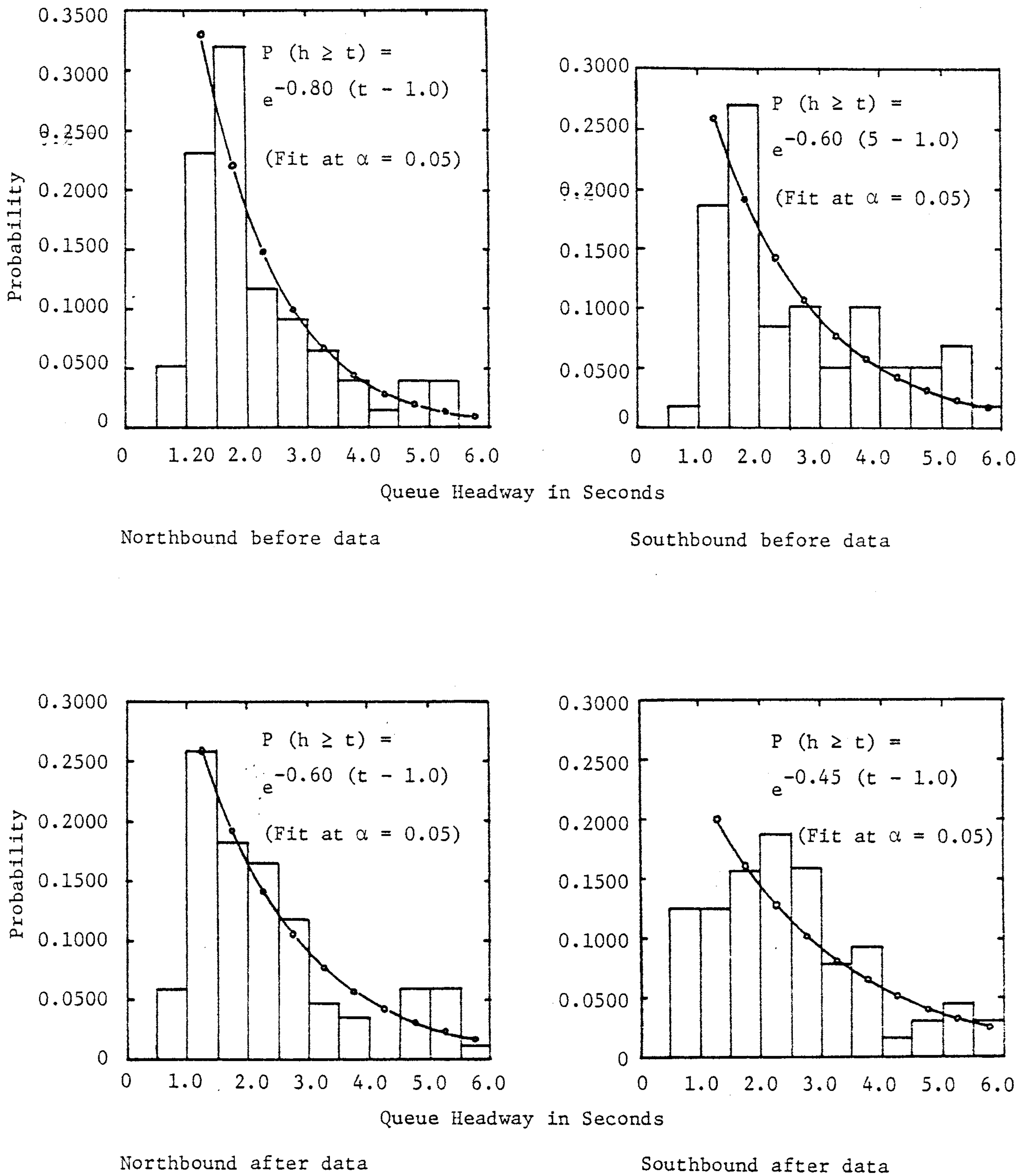
Prisk's study reports that X' is about two-thirds of G_2. (Reference 7)

ANALYSIS ON QUEUE HEADWAYS

The data on queue headways were analyzed to examine their general distribution patterns and to evaluate the impacts, if any, of different pavement marking patterns on these distributions. A queue was defined in this study as two or more vehicles traveling in the same direction, with a maximum time headway of 6 seconds between any two consecutive vehicles. The samples of queue headway used for the analyses were extracted from the data collected with the electronic data acquisition system.

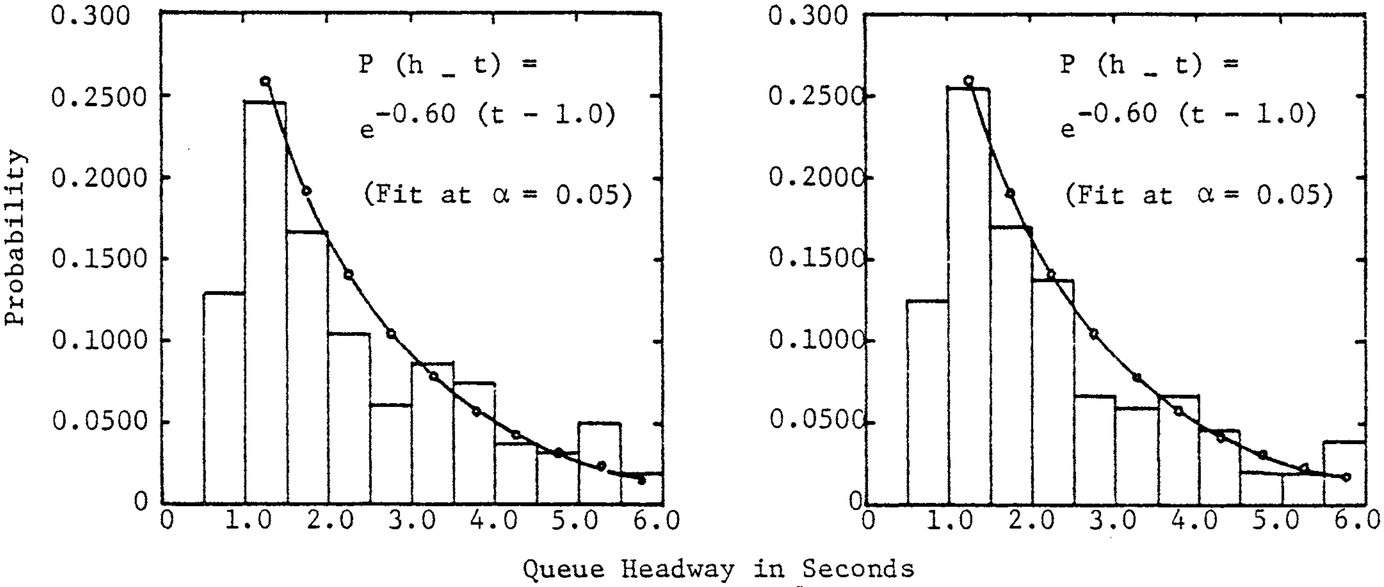
Queue Headway Distribution

Queue headway data for each lane of the study sites were grouped in 0.5-second intervals. The probability for each interval was computed and plotted in a histogram as shown in Figure 10. To develop general distribution patterns for these data, theoretical distribution curves were fitted to the actual probability data and tested using the chi-square goodness-of-fit test.



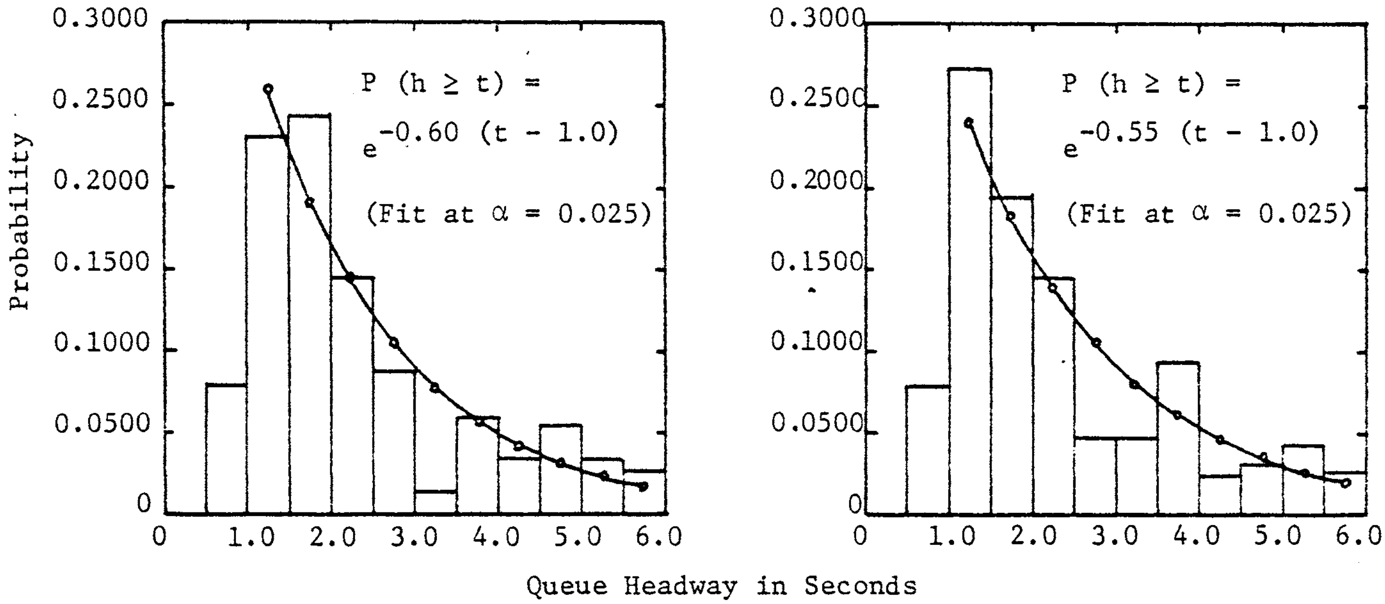
Site S - 1 on Route 501

FIGURE 10. QUEUE HEADWAY DISTRIBUTIONS AT STUDY SITES.



Eastbound before peak-hour data

Westbound before peak-hour data

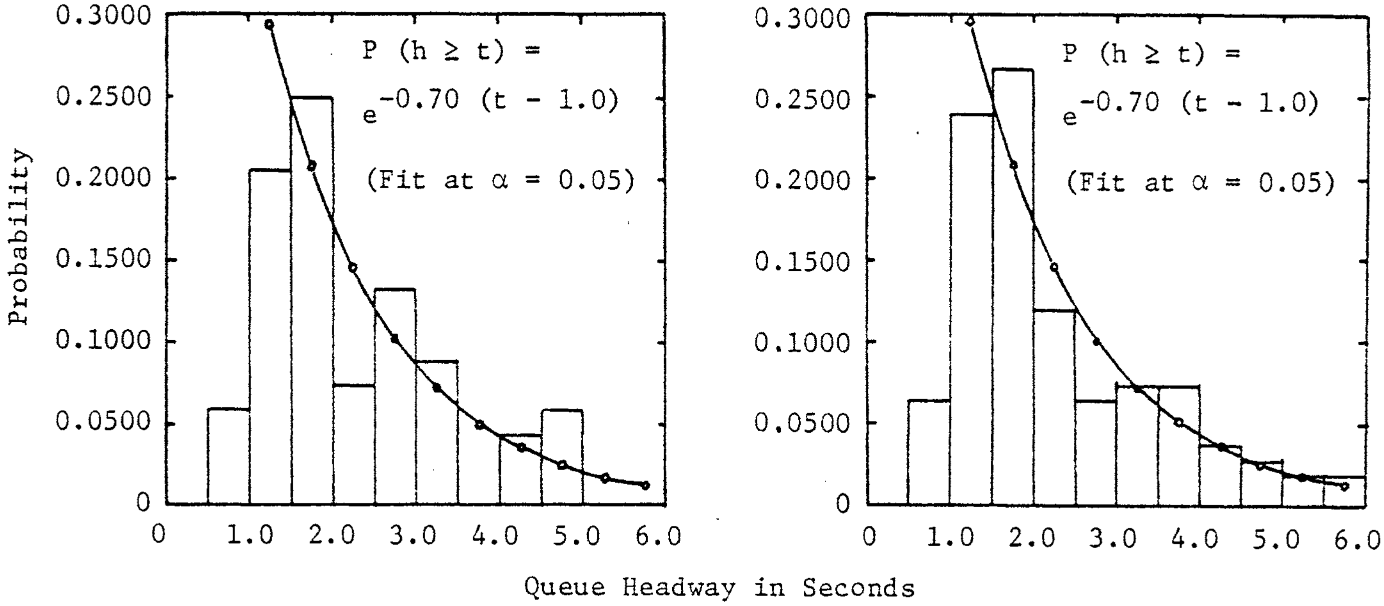


Eastbound before off-peak-hour data

Westbound before off-peak-hour data

Site S - 2 on Route 311

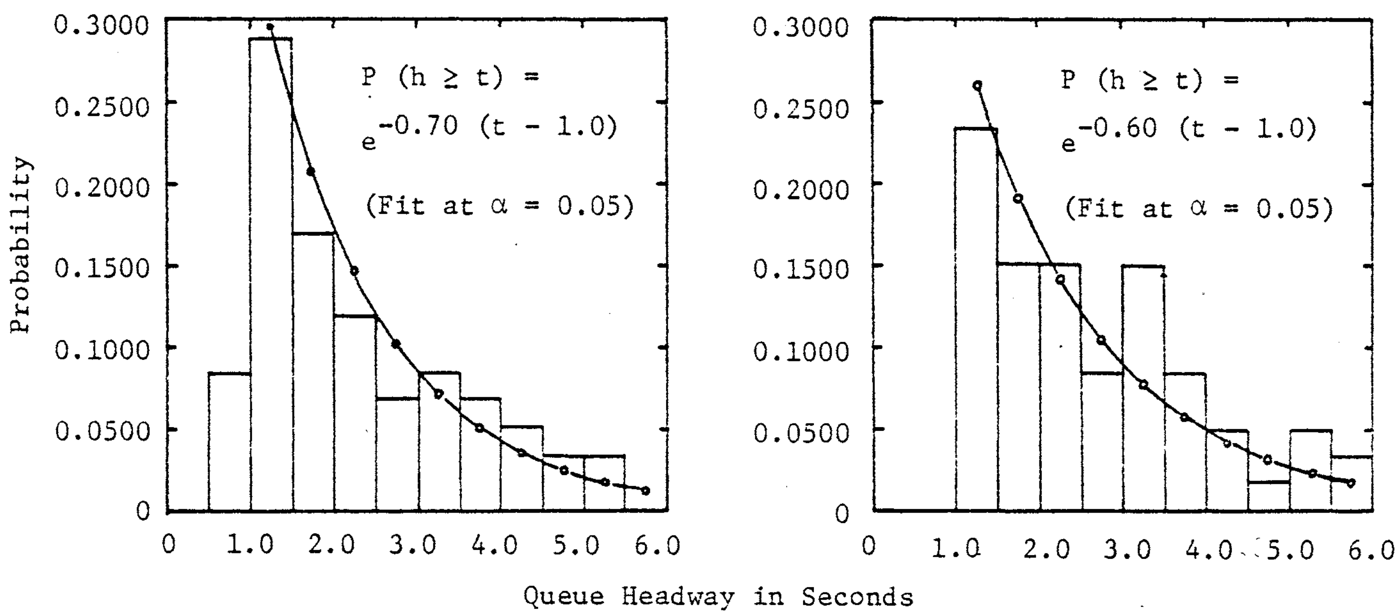
FIGURE 10. CONTINUED.



Northbound before data

Southbound before data

Site S - 3 on Route 220

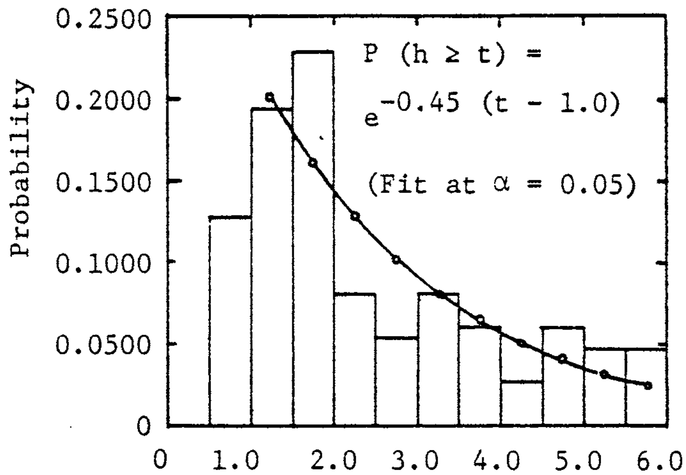


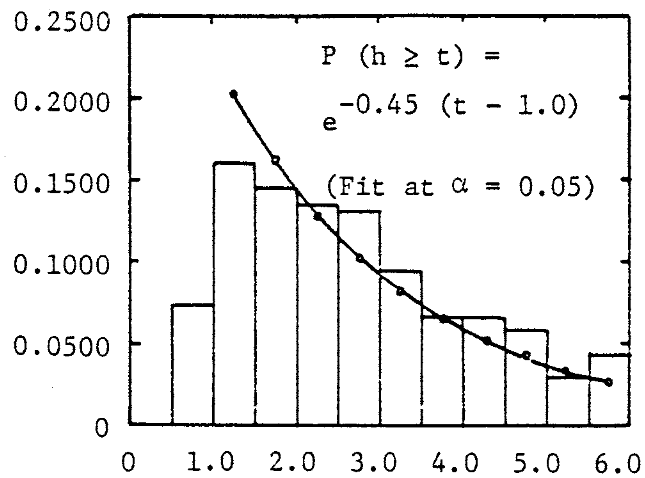
Eastbound before data

Westbound before data

Site S - 4 on Route 130

FIGURE 10. CONTINUED.

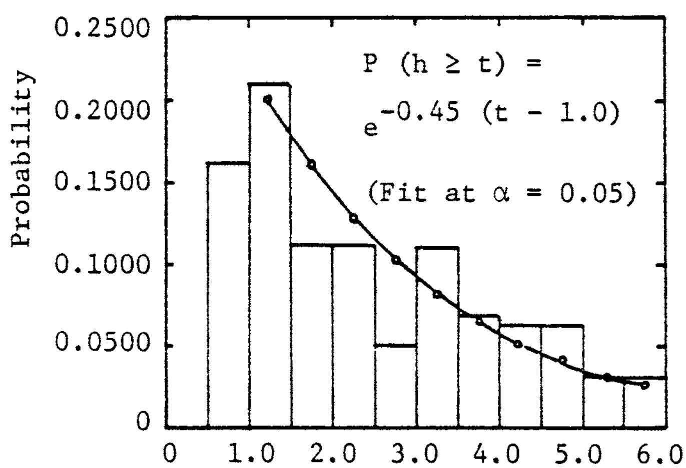


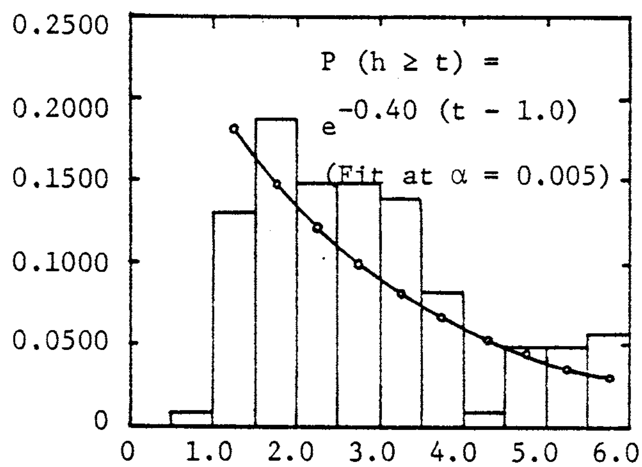


Queue Headway in Seconds

Northbound before peak-hour data

Southbound before peak-hour data





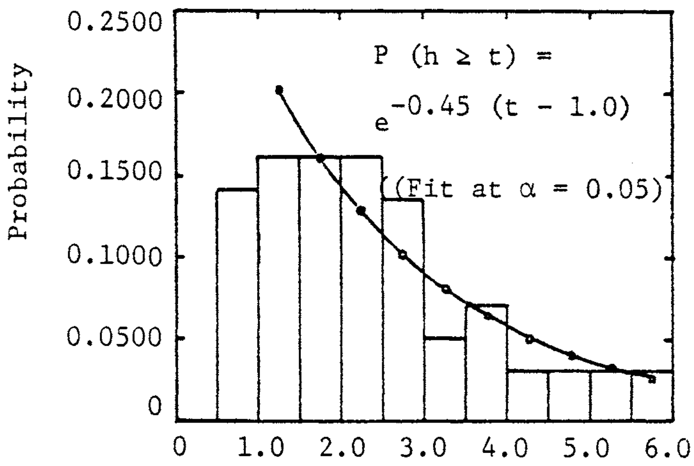
Queue Headway in Seconds

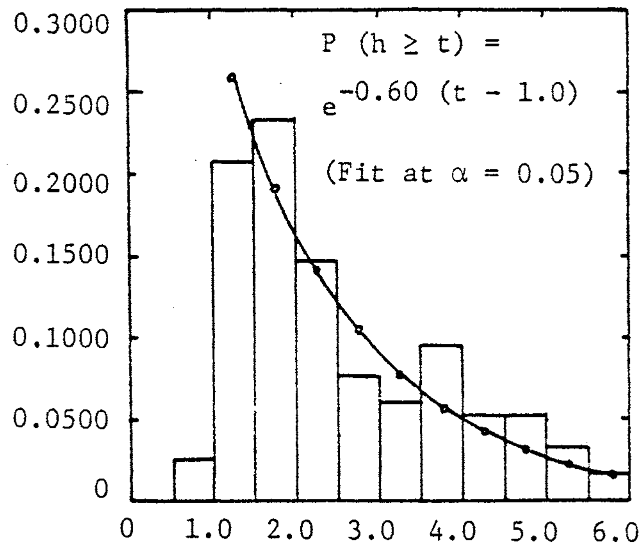
Northbound after peak-hour data

Southbound after peak-hour data

Site S - 5 on Route 116

FIGURE 10. CONTINUED.

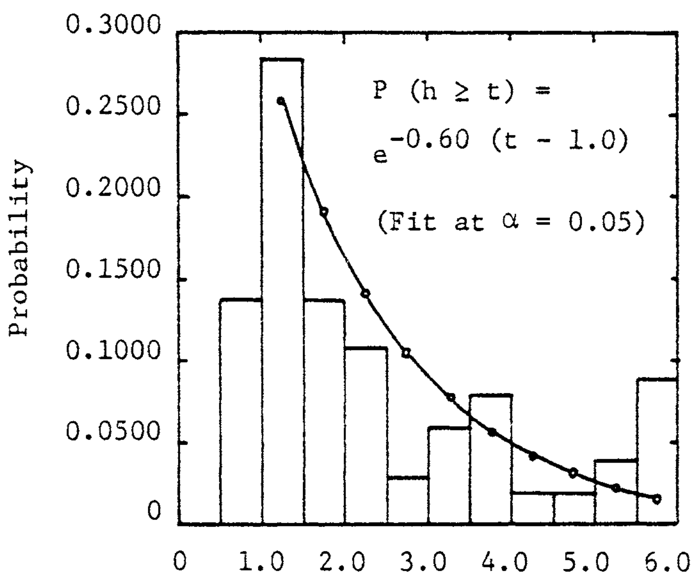


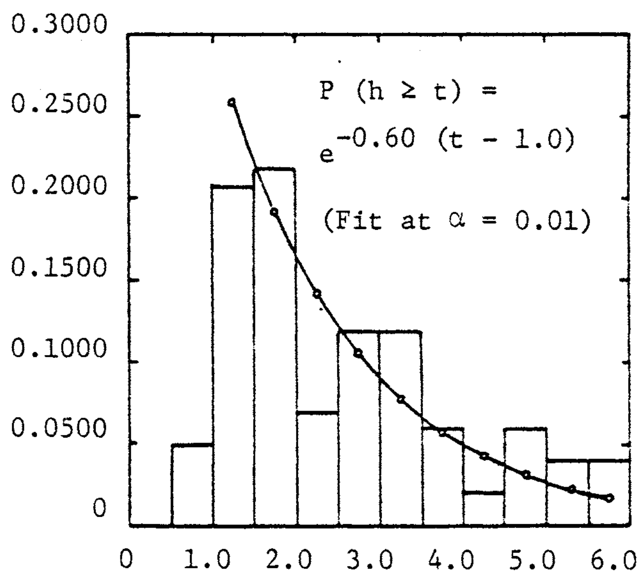


Queue Headway in Seconds

Northbound before off-peak-hour data

Southbound before off-peak-hour data





Queue Headway in Seconds

Northbound after off-peak-hour data

Southbound after off-peak-hour data

Site S - 5 on Route 116 (continued)

FIGURE 10. CONTINUED.

It was found that the shifted (1.0 second) negative exponential distribution would approximate the actual distribution most reasonably at a 5% significance level for all cases except for the off-peak before data on both directions at site S-2 and the peak and off-peak after data on the upslope (southbound) at site S-5.

The negative exponential curve fitted the data at a 2.5% significance level for the off-peak before data on the downgrade (eastbound) at Site S-2. However, as for the data on the upgrade at this site, negative exponential curves did not fit well. The negative exponential curve shown in Figure 10 (lower right, page 29) had a computed χ^2 value of 23.86 against the theoretical χ^2-value of 21.96 at a 0.5% significance level with 8 degrees of freedom. A negative exponential distribution fit the peak-hour after data on the southbound lane at site S-5 at a 0.5% significance level, whereas the off-peak-hour after data fit a negative exponential distribution at a 1.0% significance level. These theoretical distribution curves are also given in Figure 10. The constant of the negative exponential distribution ranged from -0.80 to -0.40 for both the before and after data.

Since the general characteristics of queue headway distributions did not differ among the sites with different geometric and traffic operating characteristics, the means test was conducted on the queue headways. The before data were used for this test since they provided more combinations for comparison.

First, the mean queue headways on opposite lanes at each study site were compared in pairs and Table 9 gives the results. Apart from site S-1, which has a sag-shaped vertical curve, each study site is located on a continuous slope. The results showed, however, that the difference in mean queue headways on opposite lanes was not significant at a 5% significance level, except for site S-1. The difference was not significant at a 1.0% significance level at site S-1. This result indicates that a difference in grades does not have a significant impact on the queue headway distribution.

The mean queue headways at all study sites except site S-1 were then compared in pairs to determine whether there were significant differences in the mean queue headways between the pairs of sites. These tests were carried out separately for upslope and downslope queues. The results, shown in Table 10, indicate that there was no significant difference between queue headways at a 5% significance level, except for a few pairs of upslope queue headways. It can, therefore, be concluded that, in general, the different physical characteristics among the sites did not have much influence on the queue headway distributions. The mean queue headway ranged from approximately 2.2 to 2.8 seconds.

TABLE 9

COMPARISON OF QUEUE HEADWAYS: UPSLOPE VS. DOWNSLOPE

Site No.	Route Number	Peak Hours or Off-Peak Hours (if separated)	Upslope			Downslope			Computed z-Score	Significance Test at α = 0.05 ($z = 1.96$)
			n_1	$\overline{X}_1$(sec)	S_1(sec)	n_2	$\overline{X}_2$(sec)	S_2(sec)		
S - 1	Rte. 501		59	2.65	1.33	78	2.19	1.12	2.14	Significant[a]
S - 2	Rte. 311	Peak Hours	153	2.25	1.30	163	2.32	1.45	0.45	Not Significant
		Off-Peak Hrs.	257	2.32	1.33	152	2.31	1.31	0.08	Not Significant
S - 3	Rte. 220		68	2.40	1.24	109	2.26	1.19	0.74	Not Significant
S - 4	Rte. 130		60	2.67	1.43	59	2.26	1.23	1.68	Not Significant
S - 5	Rte. 116	Peak Hours	138	2.68	1.37	149	2.47	1.38	1.30	Not Significant
		Off-Peak Hrs.	116	2.54	1.27	99	2.39	1.31	0.85	Not Significant

NOTE: The gradients at the study sites are shown below.

Only the before data were used for this comparison.

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

Site No.	Upslope	Downslope	
S - 1	(SB = - 3.2% ~ + 6.5%)	(NB = - 6.5% ~ + 3.2%)	--- Sag shaped vertical alignment
S - 2	WB = + 7.8%	EB = - 7.8%	
S - 3	NB = + 5.4%	SB = - 5.4%	
S - 4	WB = + 4.3%	EB = - 4.3%	
S - 5	SB = + 7.0%	NB = - 7.0%	

[a]This case is not significant at the 1.0% significance level.

TABLE 10

COMPARISON OF QUEUE HEADWAYS FOR ALL DATA GROUPS
AT 5% SIGNIFICANCE LEVEL

Group	S - 2 PH		S - 2 OPH		S - 3		S-4		S - 5 PH		S - 5 OPH	
	z-Score	Signif. Test	z-Score	Signif. Test	z-Score	Signif. Test	z-Score	Signif. Test	z-Score	Signif. Test	z-Score	Signif. Test
Downslope												
S - 2 PH	--	--										
S - 2 OPH	0.06	Not Sig.							SYM			
S - 3	0.37	Not Sig.	0.32	Not Sig.	--	--						
S - 4	0.31	Not Sig.	0.26	Not Sig.	0.00	Not Sig.	--	--				
S - 5 PH	0.94	Not Sig.	1.03	Not Sig.	1.30	Not Sig.	1.07	Not Sig.	--	--		
S - 5 OPH	0.40	Not Sig.	0.41	Not Sig.	0.75	Not Sig.	0.63	Not Sig.	0.46	Not Sig.	--	--
Upslope												
S - 2 PH	--	--										
S - 2 OPH	0.52	Not Sig.	--	--					SYM			
S - 3	0.82	Not Sig.	0.47	Not Sig.	--	--						
S - 4	1.98	Signif.[a]	1.73	Not Sig.	1.13	Not Sig.	--	--				
S - 5 PH	2.74	Signif.[b]	2.52	Signif.[a]	1.47	Not Sig.	0.05	Not Sig.	--	--		
S - 5 OPH	1.84	Not Sig.	1.53	Not Sig.	0.58	Not Sig.	0.59	Not Sig.	0.84	Not Sig.	--	--

NOTE: Site S-1 was excluded due to the sag-shaped vertical alignment.

PH = Peak Hours
OPH = Off-peak hours

[a]Not significant at a 1.0% significance level.

[b]Not significant at a 0.5% significance level.

Impacts of Different Pavement Marking Patterns

Using the queue headway data taken at sites S-1 and S-5, the impacts of the different pavement marking patterns upon the queue headway distribution were examined. Figure 10 shows the distribution for the before and after phases at these sites. When the before data were collected, the sites had been striped with the MPM; for the after data collection, the standard MUTCD marking patterns were used. An 800-ft. section of site S-1 was striped as a passing zone and the rest as a no-passing zone. At site S-5, the entire stretch was marked as a no-passing zone. At both sites, the approaches were marked as no-passing zones for more than a mile and connected with the adjacent sections striped with the MUTCD sanctioned marking patterns.

It was found that the general distribution characteristics did not change for the before and after data as was shown in Figure 10, (pages 28, 29, 30, 31 and 32). Although there was not much difference between the headway distributions for the two cases, it was observed that the number of very short headways found in the before data decreased and that the distribution spread toward the longer headways. These phenomena occurred for all cases except for the northbound lane of site S-5 during the off-peak hours. However, the queue headway distribution for this case was similar to the distribution for other cases with the MPM.

It can, therefore, be said that the standard MUTCD marking patterns would not only clearly indicate suitable stretches of road for passing maneuvers but also encourage motorists to refrain from driving with very short headways, as shown in the queue headway distribution. Nonetheless, the difference in mean queue headways between the before and after phases was not significant at a 5% significance level as shown in Table 11.

TABLE 11

COMPARISON OF TIME HEADWAYS IN QUEUE: BEFORE VS. AFTER

Time Period	Direction	Before			After			Computed z-Scores	Significance Test at $\alpha = 0.05$ ($z = 1.96$)
S-5		n_1	$\overline{X}_1$ (sec)	S_1 (sec)	n_2	$\overline{X}_2$ (sec)	S_2 (sec)		
Peak	NB[a]	149	2.47	1.38	162	2.45	1.46	0.12	Not Sig.
	SB[b]	138	2.68	1.37	123	2.83	1.35	0.89	Not Sig.
Off-Peak	NB[c]	99	2.39	1.73	102	2.40	1.58	0.03	Not Sig.
	SB[d]	116	2.54	1.27	101	2.57	1.37	0.16	Not Sig.
S-1									
		Before[e]			After[f]				
		n_1	X_1 (sec)	S_1 (sec)	n_2	X_2 (sec)	S_2 (sec)		
	NB	78	2.19	1.12	85	2.33	1.28	0.78	Not Sig.
	SB	59	2.65	1.33	64	2.49	1.34	0.65	Not Sig.

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

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

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

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

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

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

[f] Samples from 06:30 - 17:00

KINEMATIC PASS MODEL

The kinematic pass model was developed to investigate the correlations between the passes in the assumed scenario and the actual passes. It was first developed based on kinematic principles only, then modified for improvement by incorporating the analytical results of the actual data.

Pass Scenario

The first kinematic pass model developed was based on the scenario illustrated in Figure 11. The definitions of the distance elements in this figure will be found in Appendix C.

In developing the first pass model, the following fundamental assumptions were made.

1. Passing vehicle (P) initially travels at the same speed as that of impeding vehicle (I); i.e., V - m, where V is the desired speed of passing vehicle in ft./sec. and m the speed difference between the passing and impeding vehicles in ft./sec.

2. Passing vehicle accelerates at a constant acceleration rate α (ft./sec.^{2}), until it achieves the desired passing speed, V, in the right lane.

3. After completing the acceleration phase, passing vehicle encroaches onto the left lane and maintains the same speed, V, throughout the rest of the passing maneuver.

4. Impeding vehicle maintains the same speed, V - m, throughout the passing maneuver.

First Kinematic Pass Model

The first pass model was based on purely kinematic principles. One important assumption made for this model was that the acceleration phase (D_1) be performed entirely in the right lane and that the passing vehicle encroaches onto the left lane after the completion of the acceleration phase as shown in Figure 11. In other words, only the constant speed phase exists on the left lane. Based on this assumption, the equation for the passing distance shown below was developed and is given in Appendix C.

$$PD = D_2 + D_3$$

$$= \frac{V}{m} \left(G_1 - \frac{m^2}{2\alpha} - X\right) + \frac{V}{\;} (X + G2)$$

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 on the left lane,

α = acceleration in ft./sec.^{2},

G_1 = space headway between passing vehicle and impeding vehicle before the passing maneuver commences, in feet,

G_2 = space headway after the completion of a pass, in feet, and

X = length of impeding vehicle in feet.

Based on the assumptions mentioned in the previous subsection, a computer program was developed using FORTRAN IV. The program and its printout are found in Appendix D. This printout provides not only the passing distance but also other distance elements and important ratios between the distance elements necessary for evaluating the kinematic model.

Required Input Data

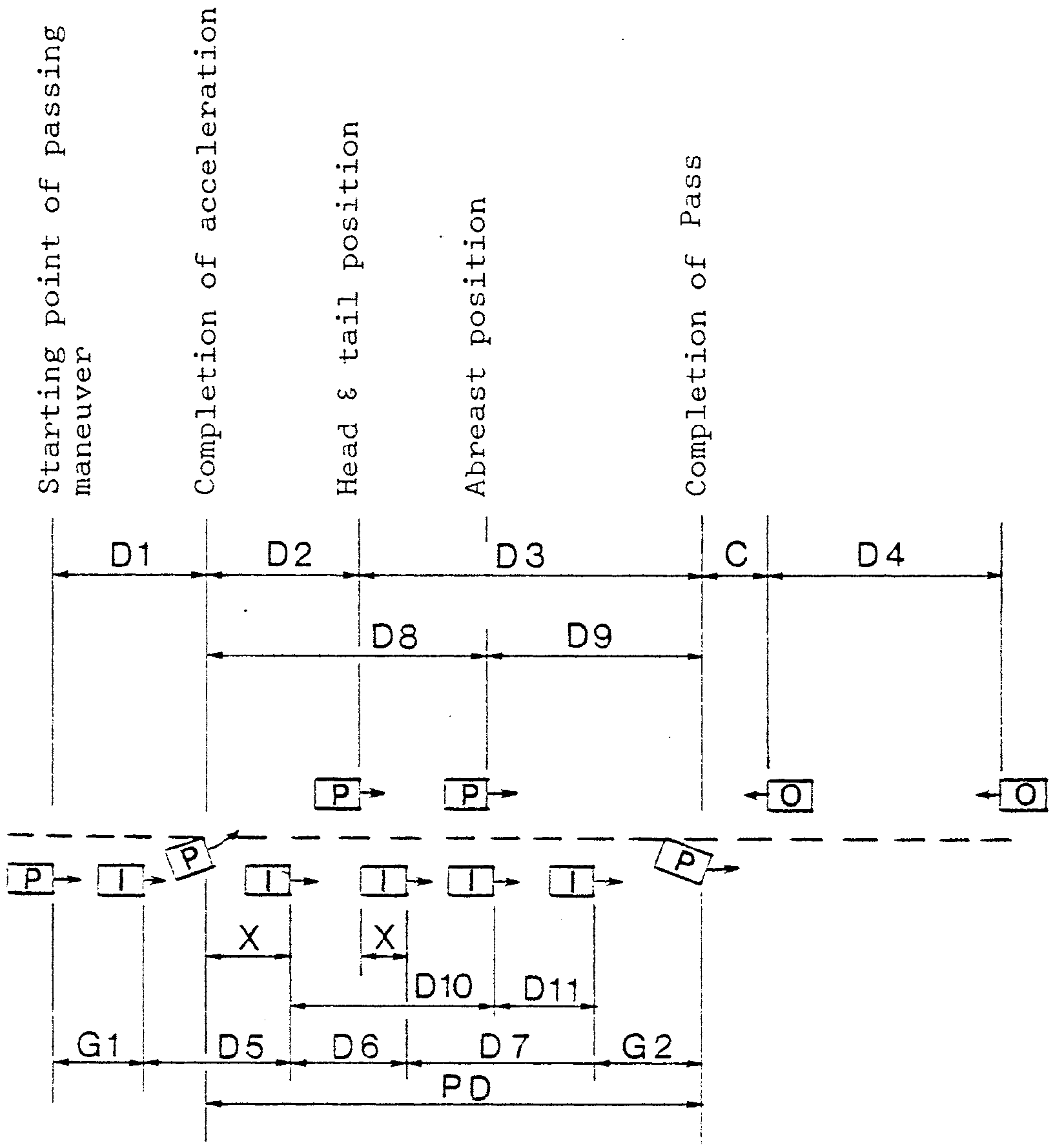
One hundred and eight cases were computed for this study, and the combinations of these cases are summarized in Table 12. In order to avoid confusion associated with unit conversions, speed was expressed in ft./sec. and the acceleration rate in ft./sec.^{2}. The following variables were used to run the pass model.

NO. = Case number (1 to 108)

TYPE = Vehicle types involved (1 for PC vs. WB - 50; 2 for PC vs. PC)

V = Passing speed in ft./sec.

FM = Speed difference in ft./sec.



P : Passing vehicle

I : Impeding vehicle

O : Oncoming vehicle

Note : The definitions of the distance elements are found in Appendix C.

FIGURE 11. PASS SCENARIO AND DISTANCE ELEMENTS OF THE PASSING MANEUVER.

TABLE 12

COMBINATIONS OF INPUT DATA USED FOR THE PASS MODEL

Type of Vehicles	Passing Speed (mph)	Passing Speed (ft./sec)	Speed Difference (mph)	Speed Difference (ft./sec)	Grade[a] (%)
PC[b] vs. WB - 50[b]	30	44.1	10.0	14.7	2.0
PC[b] vs. PC[b]	35	51.5	12.5	18.4	6.0
	40	58.8	15.0	22.1	10.0
	45	66.2			
	50	73.5			
	55[c]	80.9			

NOTE: The total number of combinations = 2 x 6 x 3 x 3 = 108 cases.

[a]Grade was input in terms of the acceleration rates. The acceleration rate changes according to grade and the speed range in which the passing vehicle travels.

[b]PC = Passenger car = x = 20 ft.; WB - 50 = semitrailer combination x = 55 t.

[c]55 mph was added as transition to higher speed driving.

GR = Grade (2.0%, 6.0%, and 10.0%)

ALPHA = Acceleration rate on upslope in ft./sec.^{2}

X = Length of impeding vehicle

G_1 = Starting space headway in feet

G_2 = After space in feet

Among these variables, ALPHA, G_1, and G_2 must be determined in advance in such a way that the values used for the individual cases must reflect the reality. The ALPHA's used for this study are shown in Table 13. These values were computed based on the acceleration rates given in reference 8. As for G_1 and G_2, it was found in this study that the gap between the passing vehicle and impeding vehicle was close to that computed by the rule of thumb as discussed in a previous section. This gap is the space between the rear bumper of the preceding vehicle and the front bumper of the following vehicle. It should not be confused with the space headway. Based on this finding, space headways G_1 and G_2 were computed as shown in Table 14. It should be noted that the speed used for the computations of both space headways is the impeding speed (V - m). In the case of the starting space headway, G_1, the speed of the passing vehicle is still the same as that of the impeding vehicle (V - m) because of the assumption made in the previous section, whereas for the "after" space headway, G_2, the vehicle to be affected by the headway is the impeding vehicle. Therefore, the speed to be used for G_2 can still be the impeding speed (V - m).

The computer printout in Appendix D provides all the input data along with the calculated distance elements and important ratios (F_1, F_2, and F_3). These ratios are defined as follows:

F_1 = Ratio of before spacing to starting space headway (X'/G_1).

F_2 = Ratio of the distance traveled by the passing vehicle from the head & tail position to the completion of the pass, to the passing distance (D_3/PD).

F_3 = Ratio of the distance traveled by the passing vehicle from the abreast position to the completion of the pass to the passing distance (D_9/PD).

It should be noted that only passenger cars were used as passing vehicles in this kinematic pass model.

TABLE 13

ACCELERATION RATES ON VARIOUS GRADES AT VARIOUS SPEEDS IN FT./SEC/SEC

Grade, %	Passing Speed (V) in MPH					
	30	35[a]	40	45[a]	50	55[a]
2.4	6.76	6.47	6.17	5.59	5.00	4.27
6.0	5.44	5.22	5.00	4.34	3.68	2.95
10.0	4.12	3.90	3.68	3.02	2.35	1.62

[a]The values in these columns were interpolated.

Source: Reference 8, p. 23.

TABLE 14

LENGTHS OF SPACE HEADWAYS G_1 AND G_2 FOR THE PASS MODEL IN FEET

G_1 = ROT + X

Speed Difference (mph)	Combination of Vehicles	Passing Speed (V) in MPH					
		30	35	40	45	50	55
10.0	PC vs. WB - 50	95	105	115	125	135	145
	PC vs. PC	60	70	80	90	100	110
12.5	PC vs. WB - 50	90	100	110	120	130	140
	PC vs. PC	55	65	75	85	95	105
15.0	PC vs. WB - 50	85	95	105	115	125	135
	PC vs. PC	50	60	70	80	90	100
G_2 = ROT + L_p							
10.0		60	70	80	90	100	110
12.5		55	65	75	85	95	105
15.0		50	60	70	80	90	100

NOTE: ROT = Gap computed by the rule of thumb in feet = (V-m) 20/10, where V and m are in MPH.

X = Length of impeding vehicle: PC = 20 ft.; WB-50 = 55 ft.

L_p = Length of passing vehicle: 20 ft.

Results of the First Kinematic Pass Model

Figure 12 shows parts of the computer printout, extracted from Appendix D. It was found that the first pass model had some deficiencies in approximating the actual passing maneuver. The following two problems were readily identified.

1. Several cases had negative distances for D_2 (see Figure 12, column D_2). This means that the passing vehicle collides with the impeding vehicle during the acceleration phase since the former is still traveling in the right lane from the assumption made.

2. In all cases, the total passing distance decreased with an increase in gradient (see Figure 12, column TOTALD). This does not conform with actual passing maneuvers performed on an upslope.

In spite of these problems, this original pass model provided vital information for the modification undertaken later. For example, the total time spent on the left lane (column TPD in Figure 12) computed by the model closely resembled that of the actual passes. Also, the values of F_1, F_2, and F_3 were found important for the purpose of comparing the kinematic pass model and the field measurements.

Modified Kinematic Pass Model

In order to alleviate these problems caused by the original assumption, the statistic F_1 taken from the field measurements was incorporated into the first model.

The field measurements of this study showed that X' was approximately 70% of G_2. Since most of the passes in this study involved passenger cars, it can be said that G_1 and G_2 are the same (see Table 14). Therefore, it was reasonable to say that X' is approximately 70% of G_1. For this reason, the modification was made based upon the assumption that

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

In other words, the passing vehicle would encroach onto the left lane when the starting space headway (G_1) of the acceleration phase is reduced to approximately 70% of its original distance (0.70 G_1). The model developed based on this assumption is given as

$$PDA = \frac{M}{\alpha}\left(V - \frac{M}{2}\right) + \frac{V}{M}\left(2\ G_1 - \frac{M2}{2\alpha}\right) - (V - M)\sqrt{\frac{0.6\ G_1}{\alpha}} -$$

**** 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	336.	[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 12. PARTIAL COMPUTER PRINTOUT OF KINEMATIC PASS MODEL.

.... PASS MODEL .....

									ORIGINAL VALUES											ADJUSTEC VALUES				
NO.	TYPE	SPEED	SPDIF	GRADE	ACCEL	X	G1	G2	D1	D2	D3	D8	D9	TPD	PD	F1	F2	F3	TOTALD	D1A	D2A	PCA	F2A	F3A
		(FT/S)	(FT/S)	(%)	(FT/S2)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(SEC)	(FT)				(FT)	(FT)	(FT)	(FT)		
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.	328.	.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 12. CONTINUED.

The detailed development of this model is given in Appendix C. The partial results of this modified model are shown in Figure 12 under "Adjusted Values." The entire results will be found in Appendix D.

The modified pass model provided better correlations with the actual passing maneuver than did the first model. These results also identified the following findings.

1. The adjusted F_3 values obtained by the pass model (D_9/PD, column F3A in Figure 12) ranged from 0.44 to 0.59, which is far less than the value (2/3) stated by Weaver and Woods(5), whose study was conducted on the passing maneuver on two-lane highways with relatively favorable geometric conditions. The field data in this study spread from 0.40 to 0.70, with the average being 0.56.

2. The adjusted F_2 values by the model (D_3/PD, column F2A in Figure 12) for the "PC vs. PC" passes ranged from 0.65 to 0.80. The field data ranged from 0.50 to 0.80, for an 0.69 average.

3. The modified passing distance (PDA) showed that although steep grades directly affect the passing distance, the difference incurred would be very small up to 50 mph. Beyond 50 mph, this difference would reach more than 100 ft. between the 2% and 10% gradients, as shown in Figure 12, column PDA.

4. Grade does affect the total passing distance, which includes the whole acceleration phase (see column TOTALD in Figure 12). This indicates that motorists require a longer time to accelerate to the desired speed on a steeper grade. The major portion of the acceleration phase takes place in the right lane.

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APPENDIX A

TRAFFIC DATA SUMMARY — SELECTED SAMPLES FOR ANALYSIS

Study Site Number	Route Number	Vehicle Type		Vehicle Speed [a]		Difference In Speed (mph)	PD (Ft.)	X' (Ft.)	Observed Distance [b]			Type of Pass
		Passing	Impeding	Passing (mph)	Impeding (mph)				C_2 (Ft.)	D_3 (Ft.)	D_9 (Ft.)	
S-1	Rte. 501	PU	PU	61.3	39.4	21.9	630	105	120	455	400	Single
		PU	PC	49.1	33.9	15.2	520	75	160	360	325	2nd of Multiple
		PC	PC	51.0	33.9	17.1	525	115	115	350	290	3rd of Multiple
		PC	PC	56.8	46.2	10.6	800	115	55	500	415	Single
		PC	PC	63.4	44.9	18.5	635	60	160	440	395	Single
		PC	T-Trailer	56.8	43.8	13.0	745	105	65	445	245	Single
		Truck	PC	48.9	34.7	14.2	720	140	130	465	400	Single
		PU	Bus	60.9	44.3	16.6	640	55	140	490	360	Single
		PC	PC	56.2	37.6	18.6	600	40	130	490	435	Single
		PC	PU	55.9	44.5	11.4	580	120	55	300	260	2nd of Multiple
S-2	Rte. 311	PU	Truck	40	7	23	500	45	60	325	275	Single
		PU	Bus	43	25	18	485	40	65	375	280	Single
		PC	Truck & PC	35	15	20	365	75	55	225	150	1st of Multiple
S-3	Rte. 220	PC	T-Trailer	47.0	21.5	25.5	540 [c]	100	160	435	335	Single
		PC	PC	53.5	35.4	18.1	495 [c]	40	115	345	265	Single
		PC	PC	54.3	39.7	14.6	515 [c]	40	70	365	290	Single
		PC	PC	56.2	34.7	21.5	460 [c]	40	95	395	240	Single
		PC	T-Trailer	40.0	21.5	18.5	425	90	100	365	215	1st of Multiple
		PC	PC	49.6	32.9	16.7	510	50	80	400	360	Single
		PC	Truck	49.1	28.6	20.5	435	70	85	290	250	Single
		PC	PC	46.8	30.6	16.2	440	30	75	340	305	Single
S-4	Rte. 130	Truck	Truck	34.8	23.6	11.2	480	120	70	360	200	Single
		Truck	T-Trailer	35.5	23.9	11.6	480	60	65	385	275	1st of Multiple
		PC	Van	47.8	32.0	15.8	345	45	70	265	210	Single
		PC	PC	48.9	29.4	19.5	370	65	65	250	185	Single
		Van	PC	43.1	28.0	15.1	350	50	40	260	220	Single
S-5	Rte. 116	PC	PC	43	37	6	610	30	110	495	415	Single
		PC	PC	42	35	7	655	45	90	480	420	Single
		PC	Truck	34	19	15	400	45	70	275	230	1st of Multiple
		PC	Truck	32	19	13	410	80	70	225	185	2nd of Multiple
		PC	Truck	38	19	19	450	45	70	260	200	3rd of Multiple
		PU	Van	44	31	13	545	40	100	380	315	Single
		PC	PC	51	35	16	525	65	110	305	265	Single
		PC	Truck	37	21	16	460	35	85	345	300	1st of Multiple
		PC	PU	40	31	9	505	35	80	315	275	1st of Multiple
		PC	PU	58	31	23	545	55	100	335	305	2nd of Multiple

NOTE: Only the samples with complete measurements necessary for intended analyses are listed in this appendix.

No data compatible with intended analyses were available at site S-6 on Rte. 39.

[a] Two traffic data recorders were used.

[b] See Appendix D for descriptions of the designations.

[c] Data taken on downslope.

APPENDIX B

SUMMARY RESULTS OF ONE-WAY ANOVA

Table B-1. One-Way ANOVA for Speed

(a) Summary of Data

	Speed Cell (mph)				
	$v < 40$	$40 \leq v < 45$	$45 \leq v < 50$	$50 \leq v < 50$	$55 \leq v$
Sample size	7	8	5	4	8
Σx_{ij} (ft.)	3,045	4,075	2,275	2,155	5,375
Mean, $x_{i.}$ (ft.)	435	509	455	539	672
Stand. Deviation (ft.)	44.1	97.0	61.4	28.1	80.0
$\Sigma (x_{ij}-x_{i.})^2$	11,650	65,823	15,100	2,369	44,847

Overall Mean $x_{..} = \frac{16,925}{32} = 528.9$ ft.

(b) ANOVA Table

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-value
Between Cell	4	256,041	64,010	12.36
Error	27	139,789	5,177	
Total	31	395,830		

$F = 12.36 > F_0 = 2.74$ (Significant at $\alpha = 0.05$)

Table B-2. One-Way ANOVA for Speed Difference

(a) Summary of Data

	Speed Difference Cell (mph)		
	$m < 15$	$15 \leq m < 20$	$20 \leq m$
Sample Size	10	16	6
Σ Xij (ft.)	5,950	7,730	2,475
Mean, Xi. (ft.)	595	483	495
Stan. Deviation (ft.)	131.3	95.6	101.6
Σ (Xij-Xi.)^2	155,250	136,971	41,250

Overall Mean X.. $= \frac{16,155}{32} = 504.8$ ft.

(b) ANOVA Table

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Value
Between cells	2	89,296	44,648	3.88
Error	29	333,471	11,499	
Total	31	422,767		

$F = 3.88 > Fo = 3.33$ (significant at $\alpha = 0.05$)

Table B-3. One-Way ANOVA for Available Sight Distance

(a) Summary of Data

	Route 501 ASD = 1,400 ft. Grade=±3.2 ~ ∓6.5		Route 8[a] ASD = 1,700 ft. Grade = level	
	Pass.Speed (mph)	Pass.Dist. (ft.)	Pass.Speed (mph)	Pass.Dist. (ft.)
Sample Size	9	9	27	27
Σ X ij	512.1	5,725	1,590.7	23,309
Mean, Xi.	56.9	636.1	58.9	863.3
Stand. Deviation	4.67	96.9	4.70	177.6
Σ (Xij-Xi.)^2	171.3	60,439	595.0	819,924

[a] Data from Reference 8.

Speed total = 2,102.8 Overall mean $X.. = \frac{2,102.8}{36} = 58.4$ mph

Passing distance total = 29,034

Overall mean $X.. = \frac{29,034}{36} = 806.5$ ft.

(b) ANOVA Table on Passing Speed

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Value
Treatment	1	27.0	27.0	1.23
Error	34	746.3	21.95	
Total	35	773.3		

$F = 1.23 < Fo = 4.13$ (not significant at $\alpha = 0.05$)

(c) ANOVA Table on Passing Distance

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Value
Treatment	1	264,552	264,552	10.217
Error	34	880,363	25,893	
Total	35	1,144,915		

$F = 10.22 > 4.13$ (significant at $\alpha = 0.05$)

Table B-4. One-Way ANOVA for Grade

(a) Summary of Data

	Rte. 130 and 220 ASD = 700' ~ 800' Grade=+4.0 ~ +5.5%		Rte. 311 and 116 ASD = 900' ~ 1100' Grade=+7.0 ~ +8.0%	
	Pass.Speed (mph)	Pass.Dist. (ft.)	Pass.Speed (mph)	Pass.Dist. (ft.)
Sample Size	7	7	13	13
Σ X ij	325.3	2,875	533.0	6,455
Mean, Xi.	46.5	410.7	41.0	496.5
Stan. Deviation	3.60	59.4	6.32	82.3
Σ (Xij-Xi.)^2	77.7	21,171	480.0	81,319

Speed total = 858.3

$$\text{Overall mean } X.. = \frac{858.3}{20} = 42.9 \text{ mph}$$

Passing Distance = 9330. $\quad$ Overall mean $X.. = \frac{9330}{20} = 466.5$ feet

(b) ANOVA Table on Passing Speed

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Value
Treatment	1	137.7	137.7	4.44
Error	18	557.7	30.98	
Total	19	685.4		

$F = 4.44 > F_o = 4.41$ (significant at $\alpha = 0.05$)

(c) ANOVA Table on Passing Distance

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F-Value
Treatment	1	33,495	33,495	5.88
Error	18	102,490	5,694	
Total	19	135,985		

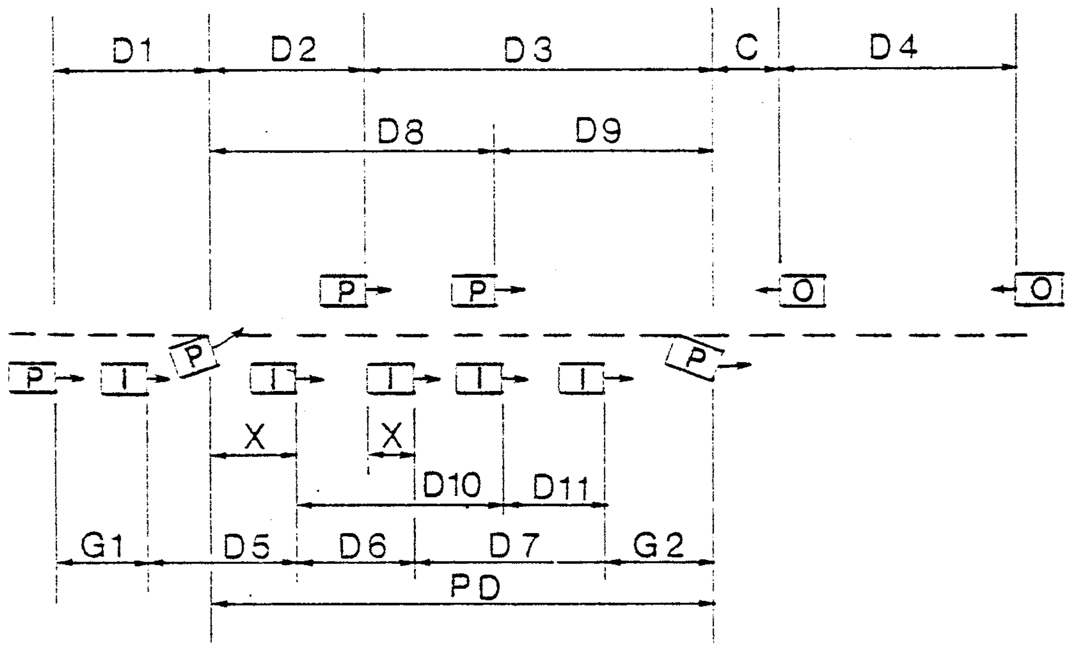
$F = 5.88 > F_o = 4.41$ (significant at $\alpha = 0.05$)

APPENDIX C

DEVELOPMENT OF A KINEMATIC PASS MODEL

First Kinematic Pass Model:

Assumption: Acceleration phase performed entirely on right lane. Passing vehicle encroaches on right lane at attainment of passing velocity.



First Assumption

$$PD = D2 + D3 + \frac{V}{M}\left(G1 - \frac{M^2}{2\alpha} - X\right) + \frac{V}{M}(X + G2)$$

Figure C-. Distance Elements of the Passing Maneuver.

Descriptions of the distance elements are given below:

D_1 = Distance traveled by passing vehicle during the acceleration phase from the speed of impeding vehicle (V-m) to the desired passing speed (V).

D_2 = Distance travelled by passing vehicle to catch up with impeding vehicle (head and trail position) from the point at which the passing speed (V) is attained.

D_3 = Distance travelled by passing vehicle from the head and tail position to completion of pass.

D_4 = Distance travelled by on-coming vehicle while passing vehicle travels from the critical position to the completion of the pass.

D_5 = Distance traveled by impeding vehicle while passing vehicle is in the acceleration phase.

D_6 = Distance traveled by impeding vehicle while passing vehicle completes D_2.

D_7 = Distance traveled by impeding vehicle while passing vehicle completes D_3.

D_8 = Distance travelled by passing vehicle to reach the abreast position with impeding vehicle from the point at which the passing speed (V) is attained.

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

D_{10} = Distance traveled by impeding vehicle while passing vehicle completes D_8.

D_{11} = Distance traveled by impeding vehicle while passing vehicle completes D_9.

G_1 = Space headway maintained by passing vehicle before it accelerates: "starting" spacing.

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

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

X = Length of impeding vehicle.

PD = Passing distance denoting the distance traveled by passing vehicle while it travels on the left lane.

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

PSD = Passing sight distance: summation of the distance between the critical position and the completing position of the pass, the clearance (C), and the distance traveled by oncoming vehicle during the same time period (D_4).

C-2. Distance Elements of the Passing Maneuver

In this subsection the equations to compute the major distance elements necessary to develop a computer program of the passing maneuver are introduced. The units used for their development are:

Speed and speed difference = ft/sec

Distance elements = ft

Acceleration and deceleration = ft/sec^2

The assumptions made to develop the following equations are found in the "Kinematic Pass Model" section of the text.

- D_1

From Figure D-1, D_1 is readily computed as follows:

$$D_1 = (V - m)t_1 + \frac{1}{2}\alpha\ t_1^{\ 2}$$

$$= (V - m)\ \frac{m}{\alpha} + \frac{1}{2}\alpha\ (\frac{m}{\alpha})^2$$

$$= \frac{m}{\alpha}\ (V - \frac{m}{2}),$$

where

m: speed difference between passing and impeding vehicles when passing vehicle is on the left lane

α: acceleration

V: speed of passing vehicle

t_1: time spent during the acceleration phase

$(t_1 = \frac{m}{\alpha})$.

o X'

From Figure C-1, X' is computed by the following equation:

$$X' = G_1 + D_5 - D_1$$
$$= G_1 + (V - m)t_1 - (V - m)t_1 - \frac{1}{2}\alpha\, t_1^{\,2}$$
$$= G_1 - \frac{1}{2}\ \frac{m^2}{\alpha}$$

o D_2

In order to derive an equation to compute D_2 it is necessary to know t_2 (time required to reach the head & tail position). t_2 is derived as shown below. According to the assumptions made, the passing vehicle maintains the same speed (V) throughout D_2.

$$D_2 + X = X' + D_6$$
$$Vt_2 + X = \left(G_1 \quad \frac{1}{2}\ \frac{m^2}{\alpha}\right) + (V - m)t_2$$
$$mt_2 = \left(G_1 \quad \frac{1}{2}\ \frac{m^2}{\alpha}\right) - X$$
$$t_2 = \frac{1}{m}\left(G_1 - \frac{m^2}{2\alpha} - X\right)$$

Using this result D_2 is computed as

$$D_2 = Vt_2 = \frac{V}{m} (G_1 - \frac{m^2}{2\alpha} - X).$$

o D_3

In order to derive an equation for calculating D_3 it is required to know t_3 (time required to complete the pass from the head & tail position). From Figure C-1, t_3 and D_3 are derived as shown below. Note that passing speed is constant (V) throughout D_3.

$$D_3 = X + D_7 + G_2$$

$$Vt_3 = X + (V - m)t_3 + G_2$$

$$t_3 = \frac{1}{m} (X + G_2).$$

Therefore, D_3 is expressed as

$$D_3 = Vt_3 = \frac{V}{m} (X + G_2)$$

$$PD = D_2 + D_3 = \frac{V}{m} (G_1 - \frac{m^2}{2\alpha} - X) + \frac{V}{m} (X + G_2).$$

o D_8

D_8 is the distance traveled by passing vehicle to reach the abreast position after the completion of the acceleration phase. As is the case for D_2, it is necessary to know the time required by passing vehicle (t_4) to travel this distance.

$$D_8 = X' + D_{10}$$

$$Vt_4 = G_1 - \frac{1}{2}\frac{m^2}{\alpha} + (V - m)t_4$$

$$t_4 = \frac{1}{m}(G_1 - \frac{m^2}{2\alpha}) .$$

Therefore,

$$D_8 = Vt_4 = \frac{V}{m}(G_1 - \frac{m^2}{2\alpha}) .$$

o D_9

The same procedure applies to computing D_9, but in this case it is t_5.

$$D_9 = D_{11} + G_2$$

$$Vt_5 = (V - m)\ t_5 + G_2$$

$$t_5 = \frac{G_2}{m} .$$

Therefore,

$$D_9 = Vt_5 = \frac{VG_2}{m} .$$

Besides these major distance elements, some auxiliary computations are required as shown in the computer program in Appendix D. Among them the following ratios are of importance in order to investigate correlations between the theoretical model and the field measurements.

F_1 = Ratio of the space headway retained by passing vehicle when it encroaches on the left lane to the space headway it maintained when it started the acceleration phase (X'/G_1).

F_2 = Ratio of the distance traveled by passing vehicle from the head & tail position till its completion of the pass to the passing distance (D_3/PD).

F_3 = Ratio of the distance traveled by passing vehicle from the abreast position till its completion of the pass to the passing distance (D_9/PD).

MODIFIED KINEMATIC PASS MODEL

Assumption: Passing vehicle encroaches on the left lane, when the starting space headway (G_1) of the acceleration phase is reduced to about seventy percent, i.e., $X' = 0.7\ G_1$.

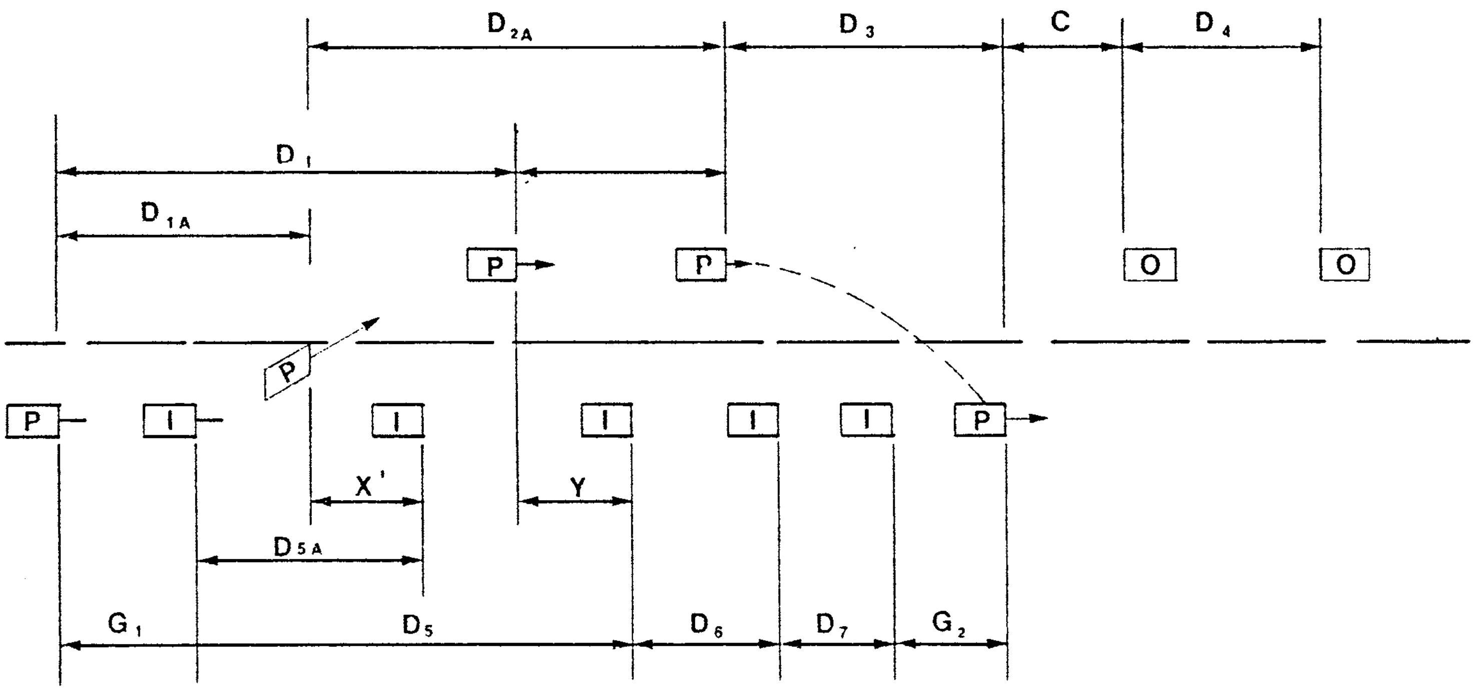


Figure C-2. Distance elements of the modified passing maneuver.

Descriptions of additional distance elements.

D_{1A} = Distance travelled by passing vehicle on right lane during acceleration phase.

D_{5A} = Distance travelled by impeding vehicle while passing vehicle is on right lane during acceleration phase.

Y = Distance between passing vehicle and impeding vehicle, when impeding vehicle attains passing speed (V).

$$PDA = D_{2A} + D_3$$

$$= D_1 + D_2 - D_{1A} + D_3,$$

let t' be the time in seconds it takes the passing vehicle to reduce the gap G_1 to 0.7 G_1.

Assuming that $X' = 0.7\ G_1$, then

$$D_{1A} + X' = G_1 + D_{5A}$$

$$(V-m)t' + \frac{\alpha}{2}(t')^2 + 0.7\ G_1 = G_1 + (V-m)t'$$

$$\frac{\alpha}{2}(t')^2 = 0.3\ G_1$$

$$t' = \sqrt{\frac{0.6\ G_1}{\alpha}}$$

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

$$= (V-m)\sqrt{\frac{0.6\ G_1}{\alpha}} + 0.3\ G_1$$

$$D_2 + X = Y + D_6$$

$$Y = G_1 + D_5 - D_1$$

$$= G_1 + (V-m)t_1 - \frac{m}{\alpha}(V - \frac{m}{2})$$

$$= G_1 + (V-m)\frac{m}{\alpha} - \frac{m}{\alpha}(V - \frac{m}{2})$$

$$= G_1 - \frac{m^2}{2\alpha}$$

$$D_2 + X = G_1 + (V-m)t_1 - \frac{m}{\alpha}(V - \frac{m}{2}) + (V-m)t_2$$

$$Vt_2 + X = G_1 + (V-m)t_1 - \frac{m}{\alpha}(V - \frac{m}{2}) + (V-m)t_2$$

$$t_2 = \frac{1}{m}(G_1 - \frac{m^2}{2\alpha} - X).$$

$$D_2 = \frac{V}{m}(G_1 - \frac{m^2}{2\alpha} - X)$$

$$D_{2A} = D_1 + D_2 - D_{1A}$$

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

$$- (V-m)\sqrt{\frac{0.6\,G_1}{\alpha}} - 0.3\,G_1$$

$$D_3 = X + D_7 + G_2$$

$$= \frac{V}{m}(X + G_2)$$

$$PDA = D_{2A} + D_3$$

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

$$- (V-m)\sqrt{\frac{0.6\ G_1}{\alpha}} + 0.3\ G_1 + \frac{V}{m}(X + G_2)$$

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

$$- (V-m)\left(\sqrt{\frac{0.6\ G_1}{\alpha}}\right) - 0.31\ G_1$$

$$= \frac{m}{\alpha}\left(V - \frac{m}{2}\right) + \frac{V}{m}\left(2\ G_1 - \frac{m^2}{2\alpha}\right)$$

$$- (V - m)\left(\frac{\sqrt{0.61\ G_1}}{\alpha}\right) - 0.31\ G_1$$

APPENDIX D

COMPUTER PROGRAM FOR THE PASS MODEL AND ITS OUTPUT


```
      PROGRAM LAB1 (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C     ********************************
C     *                              *
C     *  PASS MODEL BY MITSURU SAITO *
C     *                              *
C     ********************************
C
C********   TITLE PRINT   **********
      PRINT 50
   50 FORMAT(1H1,///,24H*****  PASS MODEL  *****,//)
      PRINT 100
  100 FORMAT(1H0,70X,15HORIGINAL VALUES,28X,15HADJUSTED VALUES,/,
     *1X,43H NO. TYPE SPEED SPDIF GRADE ACCEL   X    G1 ,
     *59H  G2    D1    D2    D3    D8     D9     TPD    PD    F1    F2    F3,
     *29H TOTALD D1A D2A  PDA F2A F3A,
     *//,10X,44H(FT/S)(FT/S)    (%)(FT/S2)(FT) (FT) (FT) (FT),
     *36H (FT)   (FT)   (FT)   (FT) (SEC)  (FT) ,15X,
     *19H(FT) (FT) (FT) (FT))
C*****  DATA INPUT  *******
      DO 5 I=1,108
      READ 10,NO,TYPE,V,FM,GR,ALPHA,X,G1,G2
   10 FORMAT(F4.0,F5.0,F6.1,F6.1,F6.0,F6.2,F3.0,F4.0,F4.0)
C*****  COMPUTATION  *****
      D1=FM*(V-FM/2)/ALPHA
      D2=V*(G1-FM**2/(2*ALPHA)-X)/FM
      D3=V*(X+G2)/FM
      D8=V*(G1-FM**2/(2*ALPHA))/FM
      D9=V*G2/FM
      T2=D2/V
      T3=D3/V
      TPD=T2+T3
      PD=D2+D3
      TDIS=D1+D2+D3
      T1=FM/ALPHA
      D5=(V-FM)*T1
```

Appendix D (Continued)

```
      F1=(G1+D5-D1)/G1
      F2=D3/PD
      F3=D9/PD
C****  F1=0.70*G1 ADJUSTMENT  ***********
      IF(F1.GE.0.70) GO TO 1000
      T4=SQRT(0.3*G1*2/ALPHA)
      D1A=(V-FM)*T4+(0.3*G1)
      D2A=D1+D2-D1A
      PDA=D2A+D3
      GO TO 15
 1000 T5=(F1*G1-0.7*G1)/FM
      D1A=D1+V*T5
      D2A=D1+D2-D1A
      PDA=D2A+D3
   15 CONTINUE
      F2A=D3/PDA
      F3A=D9/PDA
C*****  OUTPUT  ***
    5 PRINT 200,NO,TYPE,V,FM,GR,ALPHA,X,G1,G2,
     *D1,D2,D3,D8,D9,TPD,PD,F1,F2,F3,TDIS,D1A,D2A,PDA,F2A,F3A
  200 FORMAT(1H0,F4.0,F5.0,F6.1,F6.1,F6.1,F6.2,F5.0,F5.0,F5.0,F5.0,F5.0,
     *F6.0,F6.0,F5.0,F6.2,F6.0,F5.2,F5.2,F5.2,F6.0,F5.0,F5.0,F5.0,
     *F4.2,F4.2)
      END
```

Appendix D (Continued)

**** PASS MODEL *****

													ORIGINAL VALUES								ADJUSTED VALUES			
NO.	TYPE	SPEED	SPDIF	GRADE	ACCEL	X	G1	G2	D1	D2	D3	D8	D9	TPD	PD	F1	F2	F3	TOTALD	D1A	D2A	PDA	F2A	F3A.
		(FT/S)	(FT/S)	(%)	(FT/S2)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(SEC)	(FT)				(FT)	(FT)	(FT)	(FT)		
1.	1.	44.1	14.7	2.0	6.76	55.	95.	60.	80.	72.	345.	237.	180.	9.46	417.	.83	.83	.43	497.	117.	35.	380.	.91	.47
2.	1.	44.1	14.7	6.0	5.44	55.	95.	60.	99.	60.	345.	225.	180.	9.19	405.	.79	.85	.44	505.	125.	34.	380.	.91	.47
3.	1.	44.1	14.7	10.0	4.12	55.	95.	60.	131.	41.	345.	206.	180.	8.76	386.	.72	.89	.47	517.	138.	35.	380.	.91	.47
4.	1.	44.1	18.4	2.0	6.76	55.	90.	55.	95.	24.	264.	156.	132.	6.52	288.	.72	.92	.46	383.	100.	19.	283.	.93	.47
5.	1.	44.1	18.4	6.0	5.44	55.	90.	55.	118.	9.	264.	141.	132.	6.19	273.	.65	.97	.48	391.	108.	19.	283.	.93	.47
6.	1.	44.1	18.4	10.0	4.12	55.	90.	55.	156.	-15.	264.	117.	132.	5.65	249.	.54	1.06	.53	405.	120.	21.	285.	.93	.46
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
10.	1.	51.6	14.7	2.0	6.47	55.	105.	70.	100.	117.	438.	309.	245.	10.77	555.	.84	.79	.44	655.	152.	65.	503.	.87	.49
11.	1.	51.6	14.7	6.0	5.22	55.	105.	70.	124.	103.	438.	295.	245.	10.50	541.	.80	.81	.45	665.	162.	65.	503.	.87	.49
12.	1.	51.6	14.7	10.0	3.90	55.	105.	70.	166.	78.	438.	271.	245.	10.02	516.	.74	.85	.48	682.	180.	65.	503.	.87	.49
13.	1.	51.5	18.4	2.0	6.47	55.	100.	65.	120.	53.	336.	207.	182.	7.55	389.	.74	.86	.47	509.	131.	42.	378.	.89	.48
14.	1.	51.6	18.4	6.0	5.22	55.	100.	65.	149.	35.	336.	189.	182.	7.20	371.	.68	.91	.49	520.	142.	42.	378.	.89	.48
15.	1.	51.6	18.4	10.0	3.90	55.	100.	65.	200.	4.	336.	158.	182.	6.61	340.	.57	.99	.53	540.	160.	44.	380.	.88	.48
16.	1.	51.6	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.	51.6	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
19.	1.	58.8	14.7	2.0	6.17	55.	115.	80.	123.	170.	540.	390.	320.	12.07	710.	.85	.76	.45	833.	191.	102.	642.	.84	.50
20.	1.	58.8	14.7	6.0	5.00	55.	115.	80.	151.	154.	540.	374.	320.	11.80	694.	.81	.78	.46	845.	203.	102.	642.	.84	.50
21.	1.	58.8	14.7	10.0	3.68	55.	115.	80.	206.	123.	540.	343.	320.	11.27	663.	.74	.82	.48	868.	226.	102.	642.	.84	.50
22.	1.	58.8	18.4	2.0	6.17	55.	110.	75.	148.	88.	415.	264.	240.	8.56	504.	.75	.83	.48	651.	166.	70.	486.	.86	.49
23.	1.	58.8	18.4	6.0	5.00	55.	110.	75.	183.	68.	415.	243.	240.	8.21	483.	.69	.86	.50	666.	180.	70.	486.	.86	.49
24.	1.	58.8	18.4	10.0	3.68	55.	110.	75.	248.	29.	415.	205.	240.	7.55	444.	.58	.94	.54	692.	204.	73.	488.	.85	.49
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

Appendix D (Continued)

**** PASS MODEL *****

												ORIGINAL VALUES							ADJUSTED VALUES				
NO.	TYPE	SPEED	SPDIF	GRADE	ACCEL	X	G1	G2	D1	D2	D3	D8	D9	TPD	PD	F1	F2	F3	TOTALD	D1A	D2A	PDA	F2A	F3A.
		(FT/S)	(FT/S)	(%)	(FT/S2)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(SEC)	(FT)				(FT)	(FT)	(FT)	(FT)		
26.	1.	58.8	22.1	6.0	5.00	55.	105.	70.	211.	3.	333.	149.	186.	5.71	336.	.53	.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	289.	.37	1.15	.64	576.	183.	60.	392.	.85	.47
28.	1.	66.2	14.7	2.0	5.59	55.	125.	90.	155.	228.	653.	476.	405.	13.31	881.	.85	.74	.46	1036.	237.	146.	799.	.82	.51
29.	1.	66.2	14.7	6.0	4.34	55.	125.	90.	199.	203.	653.	451.	405.	12.93	856.	.80	.76	.47	1055.	256.	146.	799.	.82	.51
30.	1.	66.2	14.7	10.0	3.02	55.	125.	90.	286.	154.	653.	402.	405.	12.19	807.	.71	.81	.50	1094.	294.	146.	799.	.82	.51
31.	1.	66.2	18.4	2.0	5.59	55.	120.	85.	188.	125.	504.	323.	306.	9.50	629.	.75	.80	.49	816.	208.	104.	608.	.83	.50
32.	1.	66.2	18.4	6.0	4.34	55.	120.	85.	242.	94.	504.	291.	306.	9.02	597.	.67	.84	.51	839.	231.	104.	608.	.83	.50
33.	1.	66.2	18.4	10.0	3.02	55.	120.	85.	347.	32.	504.	230.	306.	8.09	536.	.53	.94	.57	883.	269.	110.	614.	.82	.50
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
37.	1.	73.5	14.7	2.0	5.00	55.	135.	100.	194.	292.	775.	567.	500.	14.52	1067.	.84	.73	.47	1261.	289.	198.	973.	.80	.51
38.	1.	73.6	14.7	6.0	3.68	55.	135.	100.	264.	253.	775.	528.	500.	13.99	1028.	.78	.75	.49	1292.	320.	197.	972.	.80	.51
39.	1.	73.5	14.7	10.0	2.35	55.	135.	100.	414.	170.	775.	445.	500.	12.86	945.	.66	.82	.53	1359.	386.	198.	973.	.80	.51
40.	1.	73.6	18.4	2.0	5.00	55.	130.	95.	237.	164.	599.	384.	379.	10.39	764.	.74	.78	.50	1000.	257.	144.	743.	.81	.51
41.	1.	73.6	18.4	6.0	3.68	55.	130.	95.	322.	116.	599.	336.	379.	9.73	715.	.65	.84	.53	1037.	293.	145.	744.	.81	.51
42.	1.	73.6	18.4	10.0	2.35	55.	130.	95.	503.	12.	599.	232.	379.	8.31	611.	.45	.98	.62	1114.	356.	159.	758.	.79	.50
43.	1.	73.6	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.	73.6	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
46.	2.	44.1	14.7	2.0	6.76	20.	60.	60.	80.	72.	240.	132.	180.	7.08	312.	.73	.77	.58	392.	86.	66.	306.	.78	.59
47.	2.	44.1	14.7	6.0	5.44	20.	60.	60.	99.	60.	240.	120.	180.	6.81	300.	.67	.80	.60	400.	94.	66.	306.	.78	.59
43.	2.	44.1	14.7	10.0	4.12	20.	60.	60.	131.	41.	240.	101.	180.	6.38	281.	.56	.85	.64	412.	105.	68.	308.	.78	.59
49.	2.	44.1	18.4	2.0	6.76	20.	55.	55.	95.	24.	180.	72.	132.	4.62	204.	.54	.88	.65	299.	73.	46.	225.	.80	.58

Appendix D (Continued)

**** PASS MODEL *****

NO.	TYPE	SPEED (FT/S)	SPDIF (FT/S)	GRADE (%)	ACCEL (FT/S2)	X (FT)	G1 (FT)	G2 (FT)	D1 (FT)	D2 (FT)	D3 (FT)	ORIGINAL VALUES D8 (FT)	D9 (FT)	TPD (SEC)	PD (FT)	F1	F2	F3	ADJUSTED VALUES TOTALD (FT)	D1A (FT)	D2A (FT)	PDA (FT)	F2A	F3A.
50.	2.	44.1	18.4	6.0	5.44	20.	55.	55.	118.	9.	180.	57.	132.	4.29	189.	.43	.95	.70	307.	80.	48.	227.	.79	.58
51.	2.	44.1	18.4	10.0	4.12	20.	55.	55.	156.	-15.	180.	33.	132.	3.75	165.	.25	1.09	.80	321.	89.	52.	232.	.78	.57
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
55.	2.	51.5	14.7	2.0	6.47	20.	70.	70.	100.	117.	315.	187.	245.	8.39	432.	.76	.73	.57	532.	115.	102.	417.	.76	.59
56.	2.	51.5	14.7	6.0	5.22	20.	70.	70.	124.	103.	315.	173.	245.	8.12	418.	.70	.75	.59	542.	125.	102.	417.	.76	.59
57.	2.	51.5	14.7	10.0	3.90	20.	70.	70.	166.	78.	315.	148.	245.	7.64	393.	.60	.80	.62	560.	142.	103.	418.	.75	.59
58.	2.	51.5	18.4	2.0	6.47	20.	65.	65.	120.	53.	238.	109.	182.	5.64	291.	.60	.82	.63	411.	101.	72.	310.	.77	.59
59.	2.	51.5	18.4	6.0	5.22	20.	65.	65.	149.	35.	238.	91.	182.	5.30	273.	.50	.87	.67	422.	110.	74.	312.	.76	.58
60.	2.	51.5	18.4	10.0	3.90	20.	65.	65.	200.	4.	238.	60.	182.	4.71	242.	.33	.98	.75	442.	124.	80.	318.	.75	.57
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
64.	2.	58.8	14.7	2.0	6.17	20.	80.	80.	123.	170.	400.	250.	320.	9.69	570.	.78	.70	.56	693.	149.	144.	544.	.74	.59
65.	2.	58.8	14.7	6.0	5.00	20.	80.	80.	151.	154.	400.	234.	320.	9.41	554.	.73	.72	.58	705.	161.	144.	544.	.74	.59
66.	2.	58.8	14.7	10.0	3.68	20.	80.	80.	206.	123.	400.	203.	320.	8.89	523.	.63	.77	.61	728.	183.	145.	545.	.73	.59
67.	2.	58.8	18.4	2.0	6.17	20.	75.	75.	148.	88.	304.	152.	240.	6.66	392.	.63	.78	.61	540.	132.	104.	408.	.74	.59
68.	2.	58.8	18.4	6.0	5.00	20.	75.	75.	183.	68.	304.	131.	240.	6.31	371.	.55	.82	.65	554.	144.	106.	410.	.74	.58
69.	2.	58.8	18.4	10.0	3.68	20.	75.	75.	248.	29.	304.	93.	240.	5.65	332.	.39	.91	.72	580.	164.	113.	417.	.73	.58
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
73.	2.	66.2	14.7	2.0	5.59	20.	90.	90.	155.	228.	495.	318.	405.	10.93	724.	.79	.68	.56	878.	189.	194.	689.	.72	.59
74.	2.	66.2	14.7	6.0	4.34	20.	90.	90.	199.	203.	495.	293.	405.	10.55	698.	.72	.71	.58	898.	209.	194.	689.	.72	.59

**** PASS MODEL *****

NO.	TYPE	SPEED	SPDIF	GRADE	ACCEL	X	G1	G2	D1	D2	D3	D8	D9	TPD	PD	F1	F2	F3	TOTALD	D1A	D2A	PDA	F2A	F3A.
												ORIGINAL VALUES								ADJUSTED VALUES				
		(FT/S)	(FT/S)	(%)	(FT/S2)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(SEC)	(FT)				(FT)	(FT)	(FT)	(FT)		
75.	2.	66.2	14.7	10.0	3.02	20.	90.	90.	286.	154.	495.	244.	405.	9.81	649.	.60	.76	.62	936.	245.	196.	691.	.72	.59
76.	2.	66.2	18.4	2.0	5.59	20.	85.	85.	188.	125.	378.	197.	306.	7.59	503.	.64	.75	.61	690.	170.	143.	520.	.73	.59
77.	2.	66.2	18.4	6.0	4.34	20.	85.	85.	242.	94.	378.	165.	306.	7.12	471.	.54	.80	.65	713.	189.	146.	524.	.72	.58
78.	2.	66.2	18.4	10.0	3.02	20.	85.	85.	347.	32.	378.	104.	306.	6.19	410.	.34	.92	.75	757.	222.	158.	535.	.71	.57
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
82.	2.	73.5	14.7	2.0	5.00	20.	100.	100.	194.	292.	600.	392.	500.	12.14	892.	.78	.67	.56	1086.	236.	250.	850.	.71	.59
83.	2.	73.5	14.7	6.0	3.68	20.	100.	100.	264.	253.	600.	353.	500.	11.61	853.	.71	.70	.59	1117.	267.	250.	850.	.71	.59
84.	2.	73.5	14.7	10.0	2.35	20.	100.	100.	414.	170.	600.	270.	500.	10.48	770.	.54	.78	.65	1184.	327.	257.	857.	.70	.58
85.	2.	73.5	18.4	2.0	5.00	20.	95.	95.	237.	164.	459.	244.	379.	8.49	624.	.64	.74	.61	860.	215.	186.	646.	.71	.59
86.	2.	73.5	18.4	6.0	3.68	20.	95.	95.	322.	116.	459.	196.	379.	7.83	575.	.52	.80	.66	897.	245.	192.	651.	.71	.58
87.	2.	73.5	18.4	10.0	2.35	20.	95.	95.	503.	12.	459.	92.	379.	6.41	471.	.24	.97	.81	975.	300.	215.	675.	.68	.56
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
91.	1.	80.9	14.7	2.0	4.27	55.	145.	110.	253.	356.	908.	659.	605.	15.63	1264.	.83	.72	.48	1517.	353.	256.	1164.	.78	.52
92.	1.	80.9	14.7	6.0	2.95	55.	145.	110.	367.	294.	908.	596.	605.	14.86	1202.	.75	.76	.50	1568.	404.	256.	1164.	.78	.52
93.	1.	80.9	14.7	10.0	1.62	55.	145.	110.	667.	128.	908.	431.	605.	12.81	1036.	.54	.88	.58	1704.	529.	267.	1175.	.77	.52
94.	1.	80.9	18.4	2.0	4.27	55.	140.	105.	309.	199.	703.	441.	462.	11.16	903.	.72	.78	.51	1212.	319.	189.	893.	.79	.52
95.	1.	80.9	18.4	6.0	2.95	55.	140.	105.	447.	121.	703.	363.	462.	10.20	825.	.59	.85	.56	1272.	376.	193.	897.	.78	.51
96.	1.	80.9	18.4	10.0	1.62	55.	140.	105.	814.	-86.	703.	156.	462.	7.64	618.	.25	1.14	.75	1432.	492.	237.	940.	.75	.49
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.	148.	716.	.79	.51

Appendix D (Continued)

**** PASS MODEL *****

												ORIGINAL VALUES								ADJUSTED VALUES				
NO.	TYPE	SPEED	SPDIF	GRADE	ACCEL	X	G1	G2	D1	D2	D3	D8	D9	TPD	PD	F1	F2	F3	TOTALD	D1A	D2A	PDA	F2A	F3A,
		(FT/S)	(FT/S)	(%)	(FT/S2)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(FT)	(SEC)	(FT)				(FT)	(FT)	(FT)	(FT)		
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
100.	2.	80.9	14.7	2.0	4.27	20.	110.	110.	253.	356.	715.	466.	605.	13.24	1071.	.77	.67	.56	1325.	296.	314.	1029.	.70	.59
101.	2.	80.9	14.7	6.0	2.95	20.	110.	110.	367.	294.	715.	404.	605.	12.47	1009.	.67	.71	.60	1376.	346.	314.	1030.	.69	.59
102.	2.	80.9	14.7	10.0	1.62	20.	110.	110.	667.	128.	715.	238.	605.	10.43	844.	.39	.85	.72	1511.	456.	340.	1056.	.68	.57
103.	2.	80.9	18.4	2.0	4.27	20.	105.	105.	309.	199.	550.	287.	462.	9.26	749.	.62	.73	.62	1058.	272.	237.	786.	.70	.59
104.	2.	80.9	18.4	6.0	2.95	20.	105.	105.	447.	121.	550.	209.	462.	8.29	671.	.45	.82	.69	1118.	320.	248.	798.	.69	.58
105.	2.	80.9	18.4	10.0	1.62	20.	105.	105.	814.	-86.	550.	2.	462.	5.73	464.	.00	1.18	1.00	1278.	421.	307.	857.	.64	.54
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