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Non-Permanent Pavement Markings in Work Zones

Research and Development
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FOREWORD

This report will be of interest to work zone safety engineers responsible for the application of non-permanent (short-term or temporary) pavement markings on new or temporary pavements. The research was initiated to study driver behavior in response to markings of 2-ft, 4-ft, and 10-ft (0.61-m, 1.22-m, and 3.05-m) lengths. Previous research studied various marking lengths, but only in ideal weather conditions. This research studied these markings in both day and night, and wet and dry conditions.

The results of this research show trends that motorist behavior improved as the length of the markings increased. The report supports retaining the current standards in the *Manual on Uniform Traffic Control Devices* for the use of the 10-ft (3.05-m) [minimum 4-ft (1.22-m)] stripe for lane lines.

Two copies of this report are being sent to each region, and six copies are being sent to each division office. At least four of these copies sent to the division should be sent to the State highway agency by the division office.

R. J. Betsold, Director
Office of Safety and Traffic
Operations Research and Development

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16. Abstract

This study was conducted to determine the effects of short-term pavement markings on driver performance. Three different marking patterns were tested within the scope of this study:

- 2-ft stripes with 38-ft gaps (0.61-m stripes with 11.58-m gaps)
- 4-ft stripes with 36-ft gaps (1.22-m stripes with 10.97-m stripes)
- 10-ft stripes with 30-ft gaps (3.05-m stripes with 9.14-m gaps) and edgelines.

The first two patterns are the temporary markings examined without edgelines while the third scenario is the full complement of markings, including edgelines, recommended in the MUTCD. Data were collected for all three marking patterns during day and night and under dry and wet weather conditions. The data analysis consisted of comparing a number of operational measures collected for the three marking patterns including: 1) lateral placement of the vehicle on the roadway, 2) vehicle speed within the test segment, 3) number of edgeline and lane line encroachments, and 4) number of erratic maneuvers, e.g., sudden directional changes.

This final report summarizes the effects on driver performance associated with the different marking patterns tested. The results of this study are presented to help organizations develop guidelines for short-term pavement marking policy.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

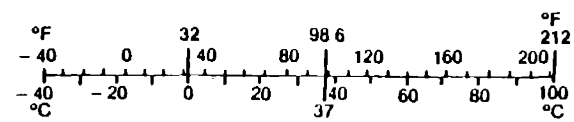
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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ADT .... average daily traffic
ANCOVA .... analysis of covariance
ANOVA .... analysis of variance
CCTV .... closed circuit television
cm .... centimeter(s)
DF .... degrees of freedom
DMI .... distance-measuring instrument
DOT .... Department of Transportation
FHWA .... Federal Highway Administration
ft .... (1) foot, (2) feet
in .... inch(es)
km .... kilometer(s)
m .... meter(s)
mi .... mile(s)
MOE .... measure of effectiveness
VCR .... videocassette recorder
VDOT .... Virginia Department of Transportation
vs. .... versus

CHAPTER 1 - INTRODUCTION

BACKGROUND

Road construction and maintenance operations, such as pavement overlay projects, often require the use of temporary pavement markings. It is imperative that such markings provide a level of guidance for the driver that will ensure safe travel. Using the concepts of positive guidance, i.e., combining traffic engineering and human factors technologies, the markings provided must enable a driver to determine the appropriate path and speed.(1) If the markings are inadequate, the driver may choose an inappropriate path or speed which may result in an accident.

Through the conduct of a large number of research and accident studies, it has been determined that the current recommended standard for permanent broken lines, either center lines or lane lanes, meets the needs of drivers in providing the appropriate level of guidance. The Manual on Uniform Traffic Control Devices (MUTCD) defines this standard for a broken line as a combination of stripes and gaps, usually in the ratio of 1:3, with the most typical pattern consisting of 10-ft (3.05-m) stripes and 30-ft (9.14-m) gaps.(2)

While the standards for permanent markings are widely accepted, there are different opinions regarding temporary, short-term, or non-permanent markings.[1] In a 1986 survey conducted by the Traffic Engineering Section of the Arizona Department of Transportation, it was discovered that 15 different temporary marking patterns were being used in 50 States as shown in table 1.(3)

This lack of consistency among States and the need to improve safety in work zones resulted in the development of the current FHWA policy on non-permanent pavement markings which is presented in appendix A. This policy was first incorporated into the MUTCD as section 6D-3 with a compliance date of January 1989. The official ruling regarding the incorporation of the new policy indicates the intention of creating uniformity and providing additional guidance with respect to non-permanent pavement markings.

Non-permanent pavement markings are defined in the MUTCD as "...those that may be used until the earliest date when it is practical and possible to install pavement markings that meet the full MUTCD standards for pavement markings." For non-permanent broken line pavement markings, the MUTCD recommends 4-ft (1.22-m) stripes and 36-ft (10.97-m) gaps, with some exceptions (see appendix A).(2) It is this recommended broken line marking which is presently being questioned. Of those 50 States surveyed, 33 used markings less than 4 ft (1.22 m) or gaps longer than 36 ft (10.97 m). It is the concern of many of these States that the newly recommended standard of 4-ft (1.22-m) stripes and 36-ft (10.97-m) gaps will significantly increase

[1] The MUTCD first used the term *temporary* pavement markings. In the 1988 edition of the MUTCD, the term was changed to *short-term*. Currently, the term *non-permanent* is being used in the revision of Part VI of the MUTCD now in the process of proposed rule making for final acceptance.

Table 1. Summary of temporary pavement marking pattern practice, 1986.[3]

Length of Stripe (ft)	Length of Gap (ft)	Striping Interval (ft)	Number of States
10	30	40	13[1]
8	32	40	1
5	95	100	1
4	36	40	8
3	37	40	1
3	77	80	1
2	18	20	1
2	38	40	6
2	48	50	6
2	78	80	1
2	98	100	1
1	24	25	2
1	39	40	6
1	74	75	1
1	79	80	1
States using separate markings for curves			7
States using temporary edgelines			26

[1] This is the standard broken line spacing recommended in the MUTCD. Two of the 13 States do not use temporary markings while 5 States allow stripes less than 4-ft (1.22-m) long under specified conditions.
1 ft = 0.305 m

project costs while not providing any additional safety benefits.

The lack of information related to non-permanent pavement markings and the benefits and costs associated with different marking patterns makes the decisions related to policy development difficult. This study was undertaken to determine the operational effects of different marking patterns on driver behavior, in order to enable future decisions regarding non-permanent pavement markings to be based on sound transportation engineering research.

STUDY OBJECTIVE AND GENERAL RESEARCH APPROACH

The objective of this study was to determine the effect of non-permanent pavement markings on driver performance. Three different marking patterns were tested within the scope of this study:

- 2-ft stripes with 38-ft gaps (0.61-m stripes with 11.58-m gaps).

- 4-ft stripes with 36-ft gaps (1.22-m stripes with 10.97-m stripes).

- 10-ft stripes with 30-ft gaps (3.05-m stripes with 9.14-m gaps) and edgelines.

The first two patterns are the temporary markings examined while the third scenario is the full complement of markings recommended in the MUTCD. Data were collected for all three marking patterns during day and night and under dry and wet weather conditions.

The data analysis consisted of comparing a number of operational measures collected for the three marking patterns. The measures of effectiveness (MOE's) selected were defined to provide a clear indication of the differences in driver performance associated with the different marking patterns and included:

- Lateral placement of the vehicle on the roadway.

- Vehicle speed within the test segment.

- Number of edgeline and lane line encroachments.

- Number of erratic maneuvers, e.g., sudden directional changes.

ORGANIZATION OF THE REPORT

This report summarizes the effects of temporary pavement markings on driver performance under both ideal and adverse lighting and weather conditions. These results provide an indication of driver performance that can be expected with each of the marking patterns examined and can be used in developing future policy related to non-permanent pavement markings.

A review of the literature related to non-permanent pavement markings is provided in chapter 2. The detailed research methodology is presented in chapter 3 while the data collection and reduction is discussed in chapter 4. Chapter 5 contains the data analysis and results while in chapter 6, a comparison of the economics associated with each of the marking scenarios is presented. The summary and conclusions are provided in chapter 7.

CHAPTER 2 - LITERATURE REVIEW

A number of studies have been conducted which examined the retroreflectivity and reliability of permanent markings and raised pavement markers (RPM's). Likewise, there have been a large number of efforts undertaken to determine the effectiveness of various work zone traffic control devices including delineators, beacons, drums, etc. However, few studies have examined the effectiveness of non-permanent pavement markings. Presented below is a summary of two recent research efforts in which a number of temporary pavement marking patterns were studied.

A 1986 study by Dudek, Huchingson, and Woods examined the effectiveness of 10 temporary marking treatments (*see table 2*) on various measures of driver performance under dry weather and road conditions only. All 10 treatments were tested during the day and the most effective 7 treatments were examined at night. The experiment consisted of having test subjects traverse a 6-mi (9.66 km) test track which included several horizontal curves and simulated a two-lane, two-way roadway with 11-ft (3.36-m) lanes, including a standard centerline and edgelines outside the treatment zones. The treatments studied were placed on four horizontal curves on the track, with the edgelines being dropped 500 ft (153 m) prior to the beginning of the curve and continuing 500 ft (153 m) after the curve.[4]

The measures of effectiveness (MOE's) used in evaluating the treatments included:

1) Speed and distance measurements, such as maximum entry speed into the curve, minimum speed while in the curve, and magnitude of the speed change.

2) Erratic maneuvers, such as lateral deviations or completely missing the curve.

3) Subjective comments and ratings of the treatments by the drivers.

All 10 treatments were tested during the daytime and yielded the following results:

- There were no practical differences between the treatments when comparing MOE's developed from speed and distance measurements. Practical differences were arbitrarily defined as at least 4 mi/h (6.44 km/h) for speed measures and 1 ft (0.30 m) for distance measures.

- The greatest number of erratic maneuvers occurred for treatments 7 and 8. Both of these treatments consisted of 2-ft (0.61-m) stripes and long gaps, although treatment 8 was supplemented with RPM's (*see table 2*).

- Treatments 2, 3, and 4 only had one or two erratic maneuvers, and were rated subjectively as least effective, most effective, and average, respectively. No erratic maneuvers were observed for treatments 5 and 10, although treatment 10, which contained a 1-ft (0.30-m) stripe, did not rate well in the subjective test given to the drivers.

- The subjective data indicated that RPM's were preferred. Of the treatments without RPM's, treatment 3 (8-ft (2.44-m) stripes with 32-ft (9.75-m) gaps) was the drivers' choice.

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Table 2. Temporary pavement marking patterns evaluated in proving-ground studies.[4]

Treatment	Description
1[1]	4-ft stripes (4 in wide) with 36-ft gaps (control condition)
2[1]	2-ft stripes (4 in wide) with 38-ft gaps
3[1]	8-ft stripes (4 in wide) with 32-ft gaps
4[1]	2-ft stripes (4 in wide) with 18-ft gaps
5[1]	Four nonretroreflective RPM's at 3 1/3-ft intervals with 30-ft gaps and one retroreflective marker centered in alternate gaps at 80-ft intervals
6[1]	Three nonretroreflective and one retroreflective RPM at 3 1/3-ft intervals with 30-ft gaps
7	2-ft stripes (4 in wide) with 48-ft gaps
8	Treatment 2 plus RPM's at 80-ft intervals
9[1]	Two nonretroreflective RPM's at 4-ft intervals with 36-ft gaps plus one retroreflective RPM centered in each 36-ft gap
10	1-ft stripes (4 in wide) with 19-ft gaps

[1] Treatments evaluated both day and night.
1 ft = 0.305 m

- Treatment 1 (4-ft (1.22-m) stripes with 36-ft (10.97-m) gaps), which was the baseline condition and is the current recommended standard in the MUTCD, was rated average in terms of effectiveness by the drivers. The erratic maneuver data also showed that this treatment resulted in relatively few complete misses of the curve, but a relatively high frequency of deviations from the centerline.

From the daytime studies, it was determined that treatments 7,8, and 10 were the least effective and were eliminated from the nighttime studies. The results for the remaining treatments tested at night in the same manner were as follows:

- Again, the speed and distance MOE's did not reveal any practical differences which could be used to rank the treatments.

- The erratic maneuver data showed no significant differences among the treatments.

- The RPM treatments were all rated highly effective by the drivers. Of the striping only treatments, treatment 3 (8-ft (2.44-m) stripes with 32-ft (9.75-m) gaps) was rated the most effective while treatment 2 (2-ft (0.61-m) stripes with 38-ft (11.58-m) gaps) was rated the least effective.

- While the baseline treatment (4-ft (1.22-m) stripes with 36-ft (10.97-m) gaps) was not the preferred choice of drivers, the performance data did not indicate any differences between that treatment and the more preferred treatments.

The second study related to this topic was an NCHRP research effort in which Dudek et al. compared 1-ft, 2-ft, and 4-ft (0.30-m, 0.61-m, and 1.22-m) temporary broken line markings in work zones during the night under dry weather conditions. The field studies were conducted at seven pavement overlay projects on two-lane, two-way roadways in four States. The sites selected had 12-ft (3.66-m) lanes, paved shoulders (4 to 10 ft (1.22 to 3.05 m)), lengths which ranged from 2,530 to 6,700 ft (771 to 2,042 m), and annual average daily traffic counts which ranged from 2,750 vehicles to 9,600 vehicles. Each site contained a tangent section and a horizontal curve of 2.0 degrees, with the exception of one with a 3.0 degree curve. The material used for the temporary centerline markings was yellow retroreflective tape.[5]

Traffic stream studies conducted included comparisons of operational measures among the three sets of markings. The MOE's evaluated included vehicle speeds, lateral distances from the centerline to the left front tire, centerline encroachments, and erratic maneuvers. The data were collected using a tapeswitch system which allowed for determining speed and lateral placement at a baseline point prior to entering the test segment, at three points in the horizontal curve, and at three points in the tangent section. This system produced a total sample of 3,697 vehicles at all 7 sites.

The results from the traffic stream studies showed no practical significant differences ($\geq$ 4 mi/h (6.44 km/h)) between the three striping patterns with respect to vehicle speeds. There were also no statistical or practical differences ($\geq$ 1 ft (0.30 m)) between the marking patterns in the comparison of lateral distance from the centerline. The remaining MOE's, centerline encroachments and erratic maneuvers, were noted as being infrequent or nonexistent.

In addition to the traffic stream studies, paid driver subjects were recruited to drive through the test segments and rate the different marking patterns. The results of this portion of the research effort showed no significant differences between the ratings for the three marking patterns. However, the general trend indicated that the 1-ft (0.30-m) stripe was ranked slightly poorer, and that the drivers preferred the longer 4-ft (1.22-m) stripe.

In summary, these two studies did not produce any strong evidence to indicate that 4-ft (1.22-m) stripes with 36-ft (10.97-m) gaps were any more effective in providing driver guidance than the 1-ft (0.30-m) stripes with 39-ft (11.89-m) gaps or 2-ft (0.61-m) stripes with 38-ft (11.58-m) gaps. However, as noted by the authors of these efforts, the research conducted was limited in scope and thus the results obtained could only be applied to those situations tested. Their suggestions for future research related to this issue included determining effectiveness of the different marking patterns under adverse weather conditions.

CHAPTER 3 - RESEARCH METHODOLOGY

ROADWAY SITUATIONS OF INTEREST

The temporary broken line pavement marking has two specific applications as stated in the MUTCD; to provide:

1) White lane lines for traffic moving in the same direction on multilane facilities, and

2) Yellow centerlines on two-lane, two-way roadways where it is safe to pass.

In this research effort only the lane line application on multilane facilities was examined. Since the objective of this study was to determine the operational effects of different lane line patterns without the effect of other markings, a divided multilane facility was selected as the test segment. Based on the FHWA policy as documented in the MUTCD, the only marking present on this type roadway under temporary conditions would be the lane line (*see figure 13 in appendix A*). On an *undivided* multilane roadway, the permanent centerline would be marked in addition to the temporary lane lines. This centerline could obviously affect driver performance and consequently, distort any results obtained regarding the effects of the lane line.

With regard to the application of centerlines on two-lane, two-way, roadways, the study by Dudek et al. previously examined temporary pavement markings on two-lane roadways (*see chapter 2*).[5] The missing element in that effort was the effect of adverse weather conditions on driver performance. Such conditions were studied in this project and provide insight into the effects associated with different marking patterns and adverse weather conditions.

ANALYSIS FRAMEWORK

The primary analysis issue addressed in this study was:

What effect does pavement marking pattern have on driver performance?

To answer this question, data were collected and analyzed for three marking patterns:

- 2-ft stripes with 38-ft gaps (0.61-m stripes with 11.58-m gaps).
- 4-ft stripes with 36-ft gaps (1.22-m stripes with 10.97-m stripes).
- 10-ft stripes with 30-ft gaps (3.05-m stripes with 9.14-m gaps) and edgelines.

The first two patterns are the temporary markings examined while the third scenario is the full complement of markings recommended in the MUTCD.

To fully explore the primary issue, two secondary issues were also addressed:

What effect does day versus night have on driver performance with respect to pavement marking pattern?

What effect does adverse weather, i.e., rain and wet road conditions, have on driver performance with respect to pavement marking pattern?

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Obtaining answers for these issues required the collection and analysis of data for all three marking patterns in periods of dry and wet weather during the day and night. This approach resulted in four light/weather conditions for each pavement marking pattern as shown in table 3.

OPERATIONAL MEASURES

The MOE's used for the evaluation of the different pavement marking patterns were selected based on the following criteria:

1) The MOE is likely to be impacted by the length of the stripe.

2) The MOE is thought to have a logical relationship to safety, i.e., can provide an indication of the risk associated with the different length stripes.

3) The MOE must be practical to obtain in the field or reduce from collected data.

Based on these criteria and the method of data collection utilized (*see chapter 4*), the operational measures selected included:

- Vehicle speed.

The speed at which a vehicle traverses the study site provides a measure directly related to the ability of the driver to determine the appropriate travel path. The inability to perform this task may result in an accident, either into another vehicle in an adjacent lane or into a fixed object off the roadway. A difference in speed between two marking patterns indicates that drivers need to travel slower under one scenario to see the markings and determine the correct path of travel. The speed selected for the analysis was the average running speed over the test segment.

- Lateral placement within the travel lane.

Typically, drivers will attempt to center their vehicles in the travel lane. The amount of deviation from this position provides an indication of accident potential, either a run-off-road type accident to

Table 3. Data collection and analysis matrix.

Stripe Length	Light Condition	Weather Condition Dry	Weather Condition Wet
2-ft	Day Night	n_{11} n_{21}	n_{12} n_{22}
4-ft	Day Night	n_{31} n_{41}	n_{32} n_{42}
10-ft	Day Night	n_{51} n_{61}	n_{52} n_{62}

1 ft = 0.305 m

the right or a sideswipe accident to the left when the vehicle is in the right lane of a multilane facility. The lateral placement measure used in the analysis was the distance from the lane line to the center of the vehicle.

- Encroachments (lane line and edgeline).

These operational measures are similar to lateral placement in that they indicate the potential of an accident resulting from inappropriate lateral position. The number of encroachments which occurred during each run was the measure used in the analysis.

- Erratic maneuvers.

Occurrences such as sudden speed or directional changes and brake applications, are performance variables which measure the ability of the driver to select the appropriate travel path. Making such maneuvers while driving through the test segment is indicative of a driver's inability to select a proper path based on the information available, i.e., pavement markings.

Detailed definitions of these measures and additional derived measures are discussed in the following chapters.

CHAPTER 4 - DATA COLLECTION AND REDUCTION

SITE SELECTION

With the help of the Virginia Department of Transportation (VDOT), several divided multilane sites scheduled for pavement overlay were identified. The site finally selected was a 4-mi (6.4-km) segment of southbound Interstate 85 extending from the intersection with Virginia State Route 903 (Exit 1) to the North Carolina State line (*see figure 1*). The test segment with the temporary markings began 400 ft (122 m) south of the Roanoke River bridge and continued to the State line with a total length of 3.1 mi (5.0 km). The terrain was relatively flat and the curvature was mild. The cross-section of the roadway, once the final markings were in place, would consist of a 10-ft (3.05-m) right shoulder, two 12-ft (3.66-m) lanes, and a 4-ft (1.22-m) left shoulder.

PAVEMENT MARKINGS

Once the pavement overlay work was completed, the placement of the markings began. The marking material used for all three patterns tested was retroreflective paint, which was the material to be used for the permanent markings once the data collection for this research study was completed. All markings were 4 in (10.3 cm) wide and were placed with a typical high-speed pavement marking truck in a rolling lane closure (*see figure 2*).

The first set of markings placed was the full complement of markings, as recommended in the MUTCD, from the beginning of the overlay segment to a point 400 ft (122 m) past the Roanoke River bridge. This was done as a safety measure to avoid having any temporary markings on the approach to the bridge where the shoulders tapered down to 2 ft (0.61 m) on either side. The first marking pattern (2-ft (0.61-m) stripe with 38-ft (11.58-m) gap) was then placed from the point below the bridge where the full complement of markings stopped to the State line. This pattern was left in place for 2 weeks while data were collected. The second pattern (4-ft (1.22-m) stripe with 36-ft (10.97-m) gap) was then placed over the 2-ft (0.61-m) pattern and left in place for 2 additional weeks while data were collected.

After the 2 week period of collection with the 4-ft (1.22-m) pattern in place, VDOT placed permanent markings consisting of 10-ft (3.05-m) stripes with 30-ft (9.14-m) gaps and edgelines. Unfortunately, they did not repeat the pattern over the existing 4-ft (1.22-m) stripes. The result was extremely long stripes, short gaps, and an inconsistent marking pattern throughout the study site. Since this produced undesirable conditions for the research effort, a second site, approximately 1 mi (1.61 km) upstream of the study segment on Interstate 85, was selected for the collection of the final set of data. The site selected was 3.5 mi (5.6 km) in length and exhibited the same curvature, terrain, and cross-section elements as the original study site. The segment had also been resurfaced just prior to the data collection effort, which resulted in approximately the same contrast between the markings and the pavement surface as exhibited on the original test segment.

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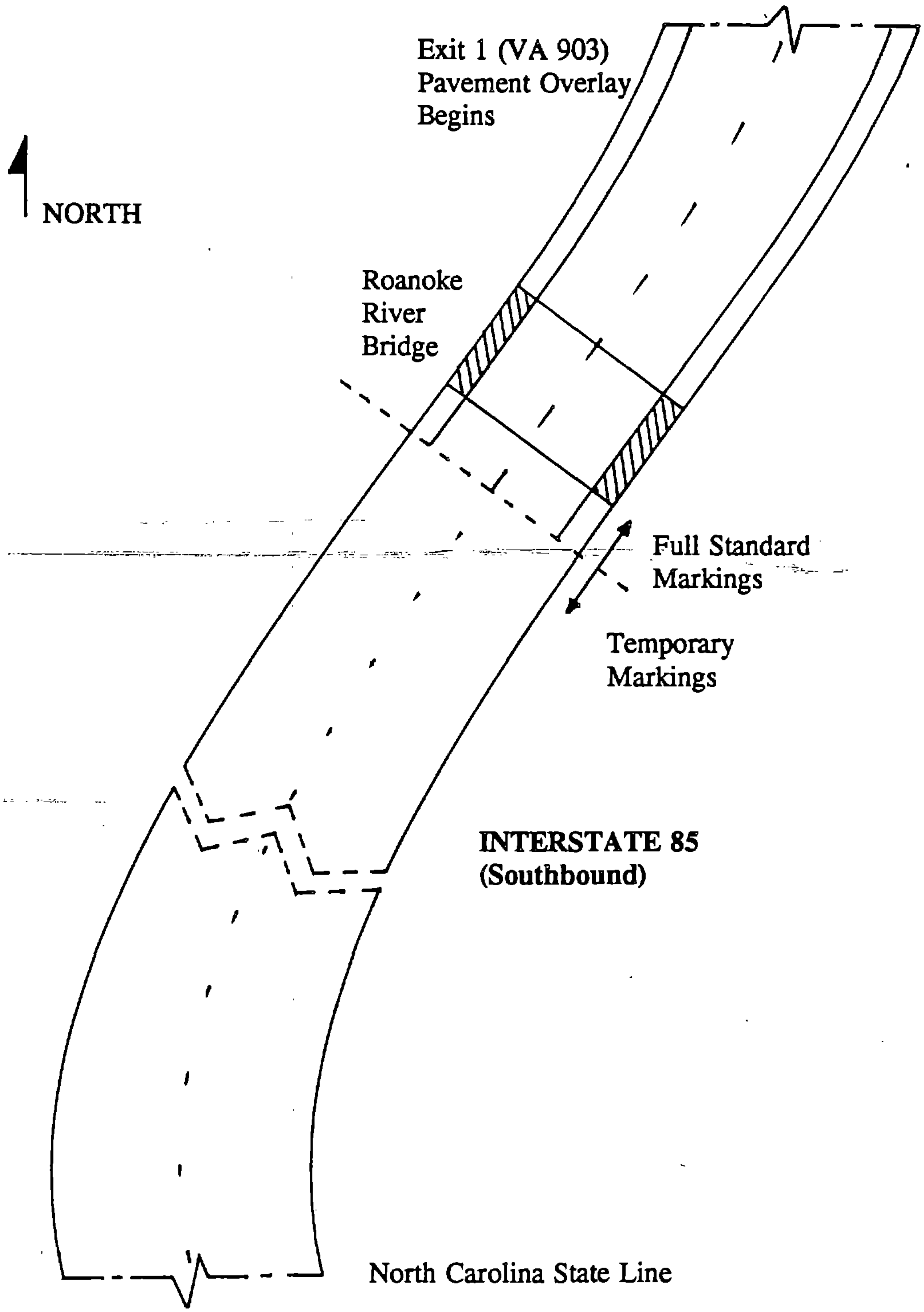


Figure 1. Field study site.

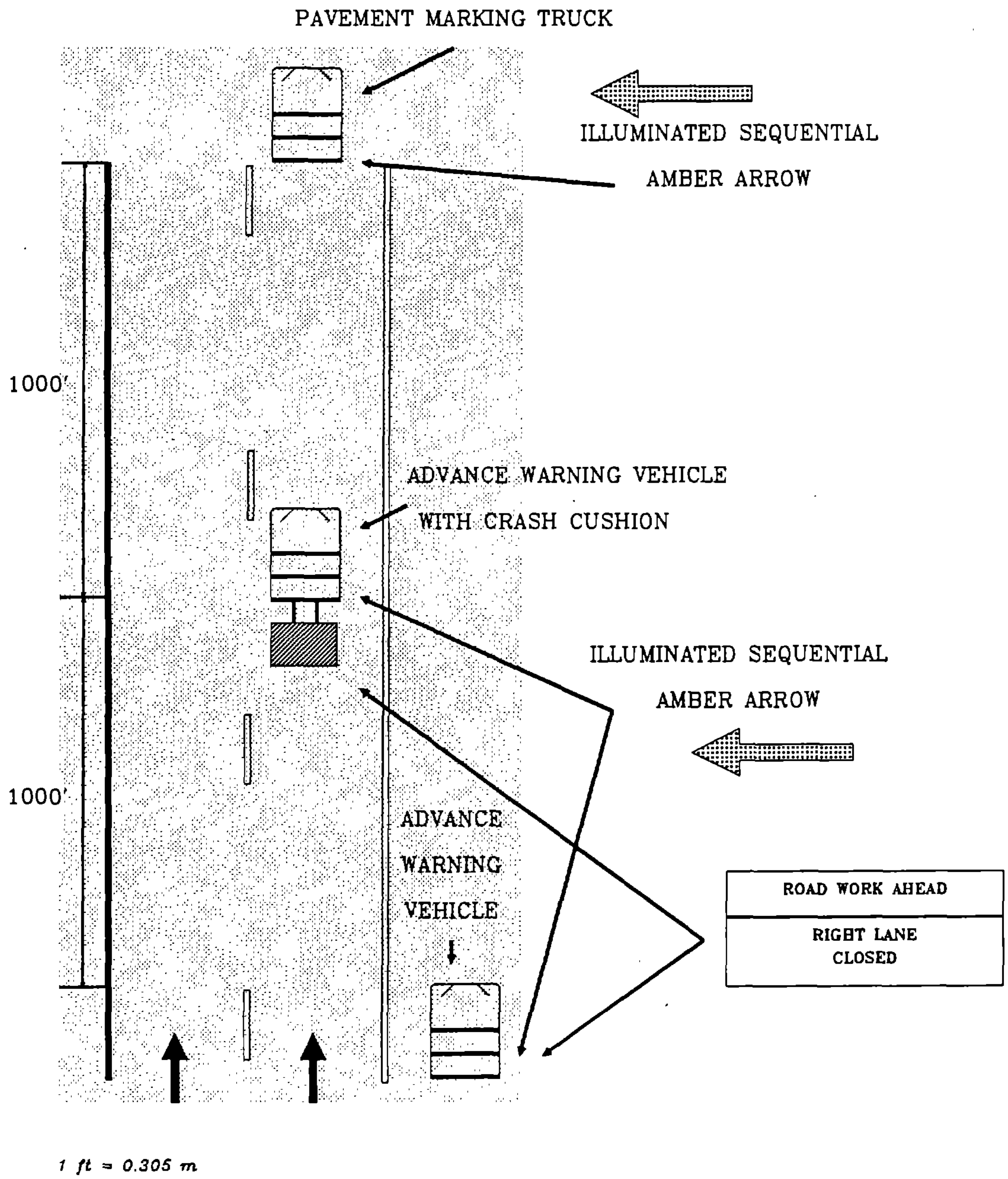


Figure 2. Rolling lane closure used in placing pavement markings.

DATA COLLECTION

The field data collection procedure consisted of a data collection van following and videotaping the operations of random cars in the traffic stream along the preselected route. This operation required one person to drive the van and one person to operate the video equipment.

Several pieces of equipment were required to record the operations of the vehicle being followed. A closed circuit television camera (CCTV), mounted inside the van, was focused on the rear of the vehicle. A second CCTV camera was focused on a distance measuring instrument (DMI) and a stopwatch inside the van. The DMI recorded the location and speed throughout the study segment while the stopwatch simply recorded elapsed time. A signal splitter was used to connect the two cameras to a videocassette recorder (VCR) which in turn, was connected to a monitor which displayed the real-time view of the vehicle being followed and the superimposed readings of the DMI and stopwatch (*see figure 3*). An external microphone was also connected to the VCR to record information such as run number, vehicle type, and any problems encountered. All of this information was recorded on a high-grade videotape.

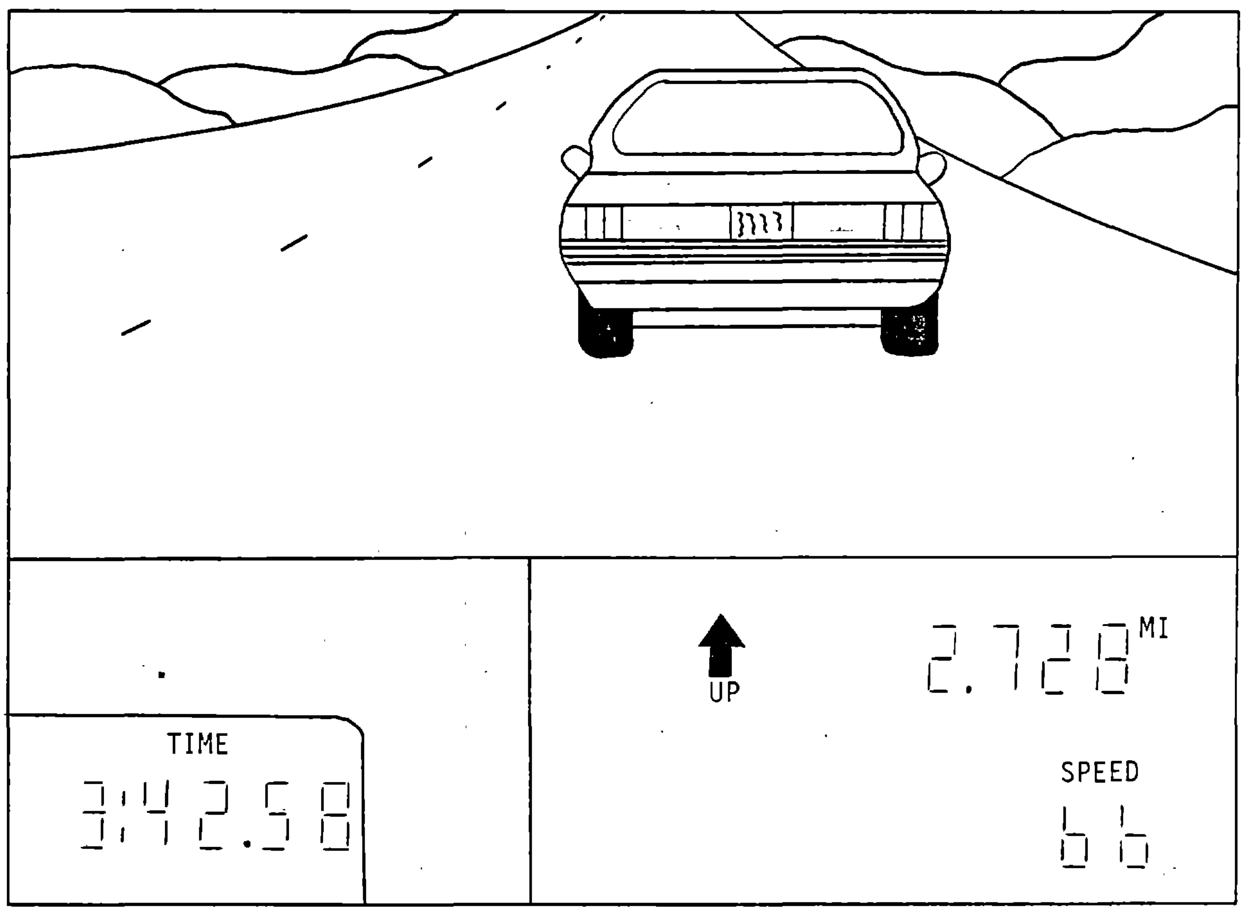


Figure 3. Real-time display of recorded data.

During the daytime data collection efforts, tinted plexiglass was mounted inside the van on all windows to conceal the video equipment from the view of other drivers in order to ensure that unbiased data were being collected. For the nighttime efforts, the plexiglass was removed and a special low-light camera was used to obtain clear images of the vehicles being followed.

Three restrictions were placed on the vehicles selected from the traffic stream for data collection:

1) In order to maximize sample size, the only vehicle type selected was a passenger car, i.e., no vans, pickups, or trucks.

2) The vehicle selected had to be isolated for at least 70 percent of the segment in order to eliminate any influences caused by other traffic.

3) The vehicle selected had to remain in the right lane for at least 70 percent of the segment since data were collected for that lane only.

The first requirement was easily determined in the field prior to beginning each run. The other requirements were not determined until the data collection run was underway or completed. These requirements resulted in some aborted runs in the field and in the elimination of runs during the data reduction task.

At an on-ramp upstream of the roadway segment being used for the study, the data collection team parked and waited for traffic stream vehicles. When a passenger car of interest passed, the team pulled in behind the vehicle and closed to the necessary following distance prior to reaching the beginning of the study segment. Preliminary information about the vehicle, such as body style, color, and taillight description, were recorded on the field data collection form (*see appendix B*) to help match the vehicles on the videotape with the appropriate run number during data reduction.

When the data collection team reached the beginning of the study segment, the DMI, stopwatch, and VCR were started and continued to run through the entire segment. The videotape provided a continuous real-time record of the operations of each vehicle followed as it traversed the roadway and allowed for the acquisition of all MOE's in the office.

For those runs conducted in wet weather, two additional variables were collected. The first of these was the rain/road conditions which subjectively gauged the intensity of the rainfall or the road conditions. The two-member data collection team jointly selected one of the following factors during each run: 1) wet road, 2) splash/spray, 3) light rainfall, 4) medium rainfall, or 5) heavy rainfall.

The second variable collected was the amount of rainfall. This measurement was determined from a stationary rain gauge which was checked every hour while data were being collected. Since this measure was averaged over the number of runs collected during an hour, it was not as indicative of actual rain conditions from a driver's perspective during a particular run as the subjective rainfall variable and thus, was not used in the analysis.

The total number of passenger cars for which data were collected in the above manner was 436. A breakdown of these runs by weather and light condition is shown in table 4. While the goal was to obtain 45 runs for each of the 12 cells, the amount of time allowed between the

Table 4. Number of passenger cars followed.

Stripe Length	Light Condition	Weather Condition Dry	Wet
2-ft	Day Night	45 45	15 28
4-ft	Day Night	45 37	20 21
10-ft	Day Night	45 45	45 45

1 ft = 0.305 m

deployment of the different marking patterns (2 weeks) and the sporadic rainfall limited the number of runs in the wet weather cells for the 2-ft (0.61-m) and 4-ft (1.22-m) patterns.

DATA REDUCTION

Obtaining the operational measures to be analyzed from the collected data consisted of three basic steps:

- Recording lateral placement from the video images.
- Recording encroachments and erratic maneuvers from the videotape.
- Determining average running speed.

The measures obtained were recorded on data reduction forms (*see appendix B*) and later entered into several data files used to conduct the analysis.

Lateral Placement

Determining the lateral placement of each followed vehicle began with the determination of vehicle width. During the field data collection effort, several measurement points were selected for this purpose. At each of these points, lane widths, shoulder widths, and distances to guardrails and other points of reference were precisely measured. Video images were produced from two of these points for each vehicle. The width of the vehicle and the width of the lane (or other reference) in the video image were measured, recorded on the data reduction form, and used to determine the actual vehicle width as follows:

$$C = (W/w) \times c$$

where: C = actual car width
W = actual reference width
c = measured car width
w = measured reference width

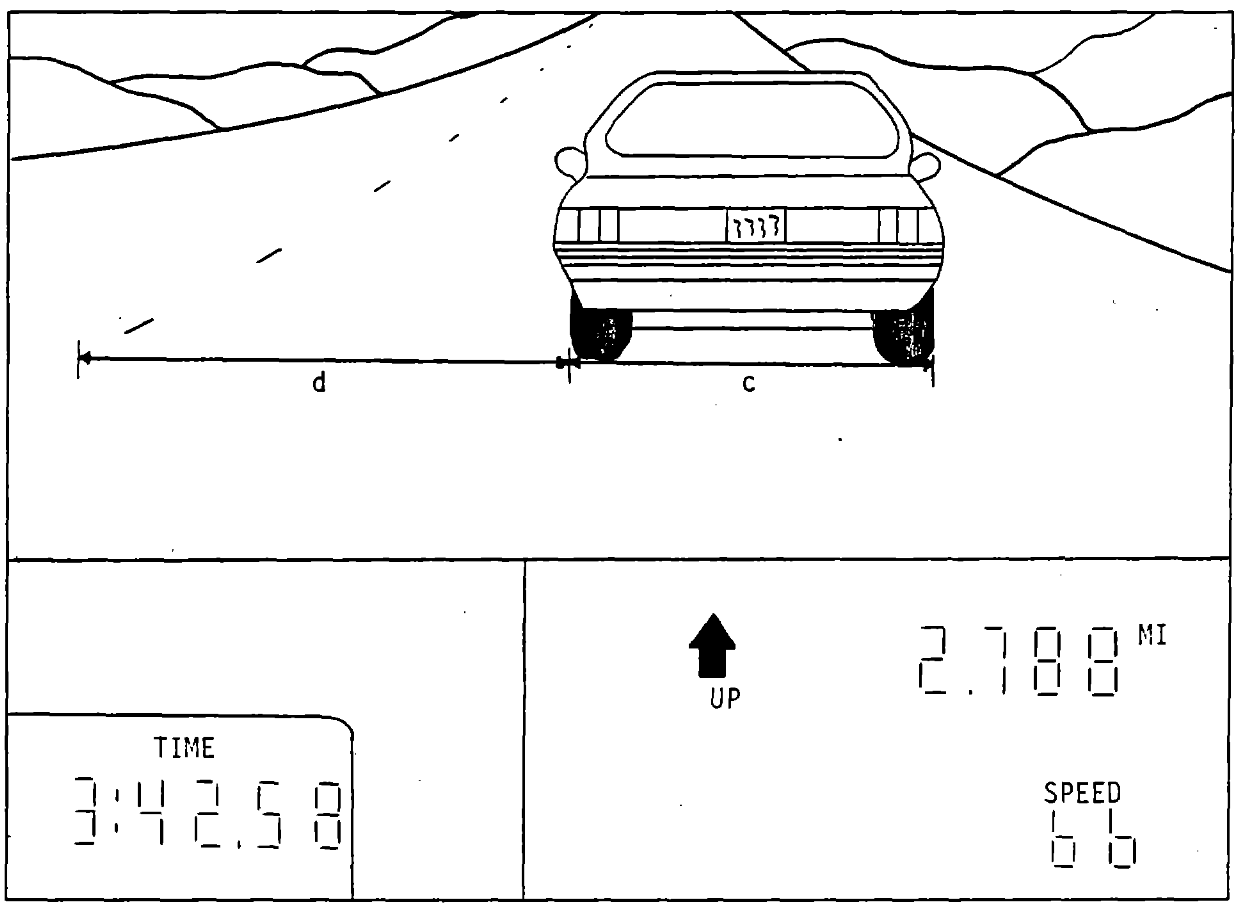
For each vehicle, video images were then produced for each point at which lateral placement was to be measured. A total of eight points were selected within the segment to be representative of the geometric characteristics of the roadway. From each video image, the car width and distance from the centerline to the outside edge of the left rear tire were measured as illustrated in figure 4 and recorded on the data reduction form. The actual distance from the centerline was then computed as follows:

$$D = (C/c) \times d$$

where:
- D = actual distance from the lane line
- C = actual car width
- c = measured car width
- d = measured distance from the lane line

Encroachments and Erratic Maneuvers

A second run through the videotape was conducted to record encroachments and erratic maneuvers. An encroachment was defined as occurring when the outside edge of the rear tire of the vehicle being followed crossed the outside edge of the



d = measured distance from lane line; c = measured car width

Figure 4. Measurements obtained from the video image for computing lateral placement.

lane line or edgeline. For the temporary marking patterns, there was no edgeline present. In those cases, the seam in the pavement served as a surrogate. This seam was consistently 12 ft (3.66 m) from the lane line and would eventually serve as a guide for placing the edgeline.

When an encroachment was observed during a run, the videotape was paused at the point where the encroachment began and the DMI value (milepost) and time (from the stopwatch) were recorded on the data reduction form along with the type of encroachment (lane line or edgeline). The videotape was then slowly advanced forward until the vehicle ended the encroachment, i.e., when the outside edge of the rear tire returned across the outside edge of the line. The time at which the encroachment ended and the DMI at that point were then recorded. The other item recorded for these events was the maximum amount of the encroachment, measured in tire widths.

While lateral placement and encroachments serve as objective measures of vehicle performance, erratic maneuvers are more subjective in nature. For purposes of this study, three events were classified as erratic maneuvers: 1) brake applications, 2) sudden speed changes of 5 mi/h (8 km/h) or greater, and 3) sudden directional changes. Each event was recorded on a form indicating the type of erratic maneuver and the location where it occurred (DMI reading).

Running Speeds

The final MOE obtained from the videotape was the average running speed. At the start of the second run through the tape, the time at which the vehicle entered the test segment (shown on the stopwatch) was recorded. Likewise, the time at which the vehicle exited the segment was also recorded. Using these values and the known distance between the two points (obtained from the DMI), the average running speed was calculated for each vehicle followed.

CHAPTER 5 - DATA ANALYSIS AND RESULTS

As discussed in chapter 3, the primary objective of the data analysis was to determine if there are any differences in driver performance that can be attributed to the different pavement marking patterns tested. These patterns are identified by the independent variable name **MARK** in the subsequent analyses and include:

- 2-ft stripes with 38-ft gaps (0.61-m stripes with 11.58-m gaps).
- 4-ft stripes with 36-ft gaps (1.22-m stripes with 10.97-m gaps).
- 10-ft stripes with 30-ft gaps (3.05-m stripes with 9.14-m gaps) and edgelines.

In addition to determining the effects of the marking pattern itself, it was also of interest to determine if day versus night and/or weather conditions affected driver performance as a function of the different marking patterns. For the following analyses, day versus night is noted by the variable **LIGHT**, while weather conditions, consisting of dry and wet, are identified by the variable **WTHR**. An additional variable which combines these environmental conditions, **COND**, was also created and includes four levels:
1) Day/Dry, 2) Day/Wet, 3) Night/Dry, and 4) Night/Wet. Finally, a subjective, but more precise, variable for wet weather conditions was used in some analyses and is noted by the label **RAIN**. This variable indicates the intensity of the rainfall using the five subjective categories discussed in chapter 4.

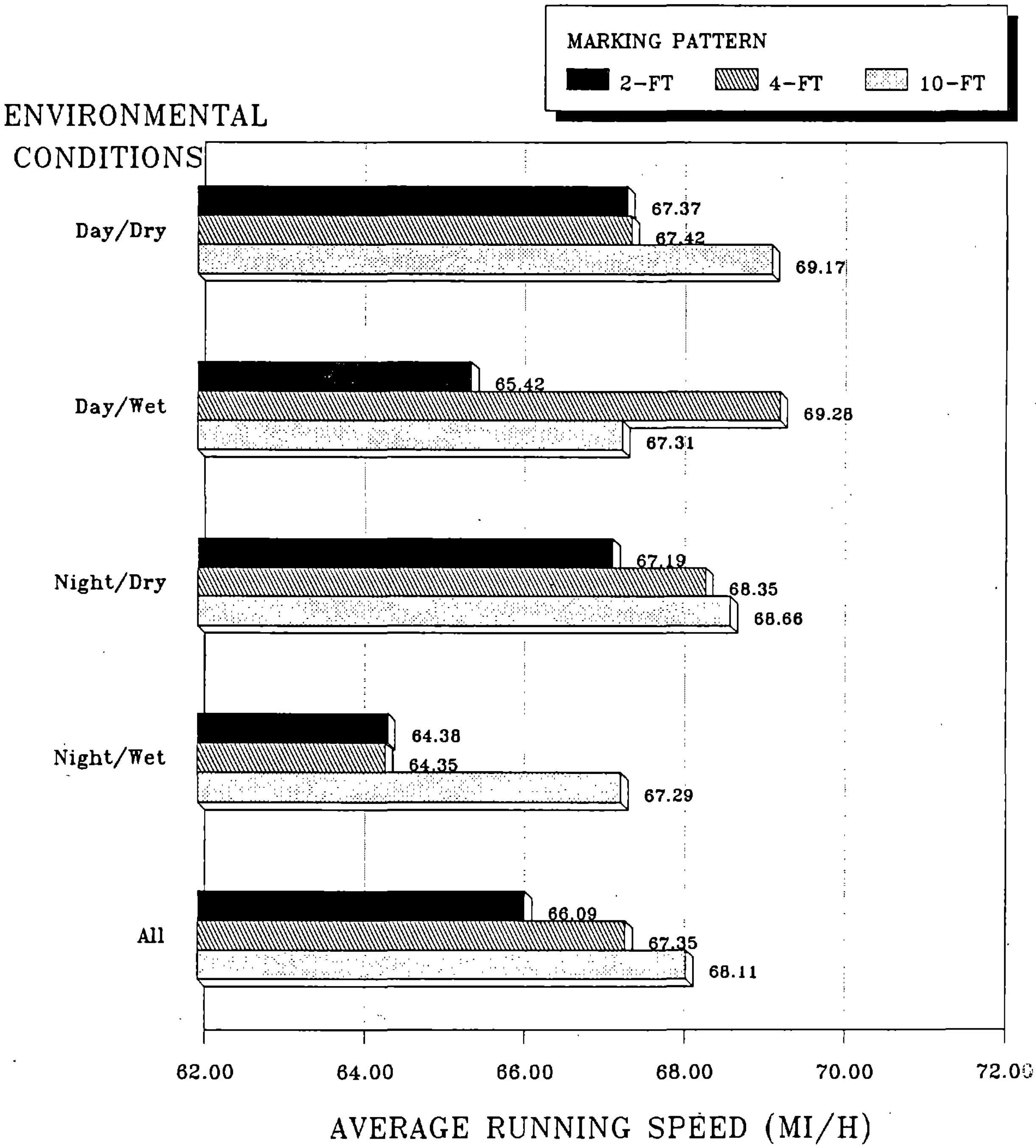
Prior to conducting statistical tests to determine the significance of the various operational measures, several tests were conducted to ensure that the data met the necessary assumptions for the statistical procedure being used, e.g, normality. The results of these tests are provided in appendix C. All procedures used in the final analysis either met the required assumptions or the data were transformed to correct for detected problems.

For many of the comparisons, analysis of variance (ANOVA) was the selected statistical procedure. A 95 percent confidence level was selected to determine if a class variable, e.g, pavement marking pattern, had a significant effect on an MOE. In examining the results below, a p-value of 0.05 or less indicates there is a significant effect of the class variable on the dependent variable tested while a p-value greater than 0.05 means there is no significant difference in the dependent variable caused by the class variable.

ANALYSIS OF VEHICLE SPEEDS

The speed variable analyzed was the average running speed (**SPEED**) which was computed for each vehicle followed as discussed in chapter 4. Shown in figure 5 are the mean running speeds for each pavement marking pattern and environmental condition.

To examine the differences among the speeds, a two-way analysis of variance (ANOVA) was run with pavement marking pattern and environmental condition as class variables. The results from the analysis are shown in table 5 and indicate that both marking pattern and environmental condition are significant factors ($P \leq 0.001$) on average running speed. The interaction



1 mi/h = 1.61 km/h; 1 ft = 0.305 m

Figure 5. Average running speeds.

Table 5. ANOVA results for average running speed (SPEED) with class variables marking pattern (MARK) and environmental condition (COND).

Significance of Class Variables

Effect	DF[1]	Mean-Square	F-ratio	P-value
COND	3	152.80	7.662	< .001
MARK	2	136.96	6.868	.001
COND*MARK	6	36.22	1.816	.094

Means by Factor Levels

MARK	SPEED (mi/h)	COND	SPEED (mi/h)
2-ft	66.09	Day/Dry	67.97
4-ft	67.35	Day/Wet	67.34
10-ft	68.11	Night/Dry	68.07
		Night/Wet	65.34

[1] Degrees of Freedom

1 ft = 0.305 m; 1 mi/h = 1.61 km/h

between the two variables (COND*MARK) proved not to be significant (P=0.094), indicating that average running speeds for the three marking patterns tested are consistently different across environmental conditions.

The significant impact of pavement marking pattern on average running speeds required further analysis to determine how each pattern contributed to this finding. Accordingly, paired comparisons between the three marking patterns were made using the Bonferroni multiple comparison method with a group confidence interval of 90 percent, which results in individual confidence intervals of 96.67 percent. The results, shown in table 6, indicate the following:

- Average running speed under the 10-ft (3.05-m) scenario is significantly higher than for the 2-ft (0.61-m) marking pattern, but is not significantly different from the 4-ft (1.22-m) pattern.

- The differences between average running speeds for the 2-ft and 4-ft (0.61-m and 1.22-m) marking patterns proved not to be significant.

The results from the ANOVA also indicated a highly significant effect of environmental conditions on average running speed. The parameters included in these conditions were two levels of light (day and night) and two levels of weather (dry and wet). Examining the raw data, it became clear that the influence of weather may be a greater factor on speeds than light conditions, and that the differences in weather conditions could be better defined with the variable RAIN, rain intensity. This variable contained five subjective categories as defined in chapter 4. In order to increase the sample size, these

Table 6. Results of Bonferroni multiple comparison method for average running speed (SPEED).

Means by Factor Levels		Comparison Results
MARK	SPEED (mi/h)	
2-ft	66.09	$-0.39 \le \beta_{10}-\beta_4 \le 1.91$
4-ft	67.35	$0.87 \le \beta_{10}-\beta_2 \le 3.17$*
10-ft	68.11	$-0.03 \le \beta_4-\beta_2 \le 2.55$

* Significant with a confidence interval of 96.67 percent.
1 ft = 0.305 m; 1 mi/h = 1.61 km/h

categories were collapsed into three levels: 1) Dry, 2) Moderate (wet road, splash and spray, light rainfall), and 3) Intense (medium and heavy rainfall). An analysis of covariance (ANCOVA) was then run with rain intensity as the covariate and marking pattern and light condition as class variables. The results confirmed previous analysis results, showing marking pattern to be a significant factor and light condition to be nonsignificant (*see table 7*). The covariate, rain intensity, also proved to be a highly significant factor ($P < 0.001$) on average running speed.

The interaction between marking pattern and rain proved to be nonsignificant ($P=0.965$), indicating the appropriateness of using RAIN as a covariate. The other interaction terms also proved to be nonsignificant.

The effect of rain on the differences in speeds between the three marking patterns is shown in the contrast comparisons in table 7 and can be summarized as follows:

- There were significant differences ($P=0.001$) in speeds between the 10-ft (3.05-m) marking pattern and the 2-ft (0.61-m) pattern.

- There were no significant differences ($P=0.184$) in speeds between the 10-ft (3.05-m) and 4-ft (1.22-m) marking patterns.

- The differences in speeds between the 2-ft and 4-ft (0.61-m and 1.22-m) patterns was not significant ($P=0.073$) at the 95 percent confidence level. This difference was significant at the 90 percent level which does indicate some small differences between the two marking patterns when combined with the effects of rain.

ANALYSIS OF MEAN LATERAL PLACEMENT

For this analysis, an operational measure of lateral placement was selected that would be representative of the typical driver. Since it is believed that most drivers tend to position their vehicles in the center of the travel lane, the MOE selected was the distance from the lane line to the center of the vehicle. This operational measure, **CDIST**, was obtained by adding the distance from the lane line to the outside of the left rear tire and half the vehicle width. For the 12-ft (3.66-m) lanes used in this study, CDIST has an expected average value of 6.0 ft (1.83 m). Shown in figure 6 are the values of the MOE for each marking pattern and environmental condition.

Prior to conducting the ANOVA for this MOE, tests for normality and heteroscedasticity were conducted and revealed problems in both areas. Several transformations of the data were attempted to correct for the problems (*see appendix C*).

Table 7. ANCOVA results for average running speed (SPEED) with covariate rain intensity (RAIN).

Significance of Class Variables

Effect	DF[1]	Mean-Square	F-ratio	P-value
MARK	2	68.95	3.411	.034
LIGHT	1	2.21	0.110	.741
LIGHT*MARK	2	0.12	0.006	.992
LIGHT*RAIN	2	27.35	1.353	.245
MARK*RAIN	4	0.73	0.036	.965

Significance of Covariate

Effect	DF[1]	Mean-Square	F-ratio	P-value
RAIN	1	334.06	16.526	<.001

Means by Factor Levels

MARK	SPEED (mi/h)
2-ft	66.09
4-ft	67.35
10-ft	68.11

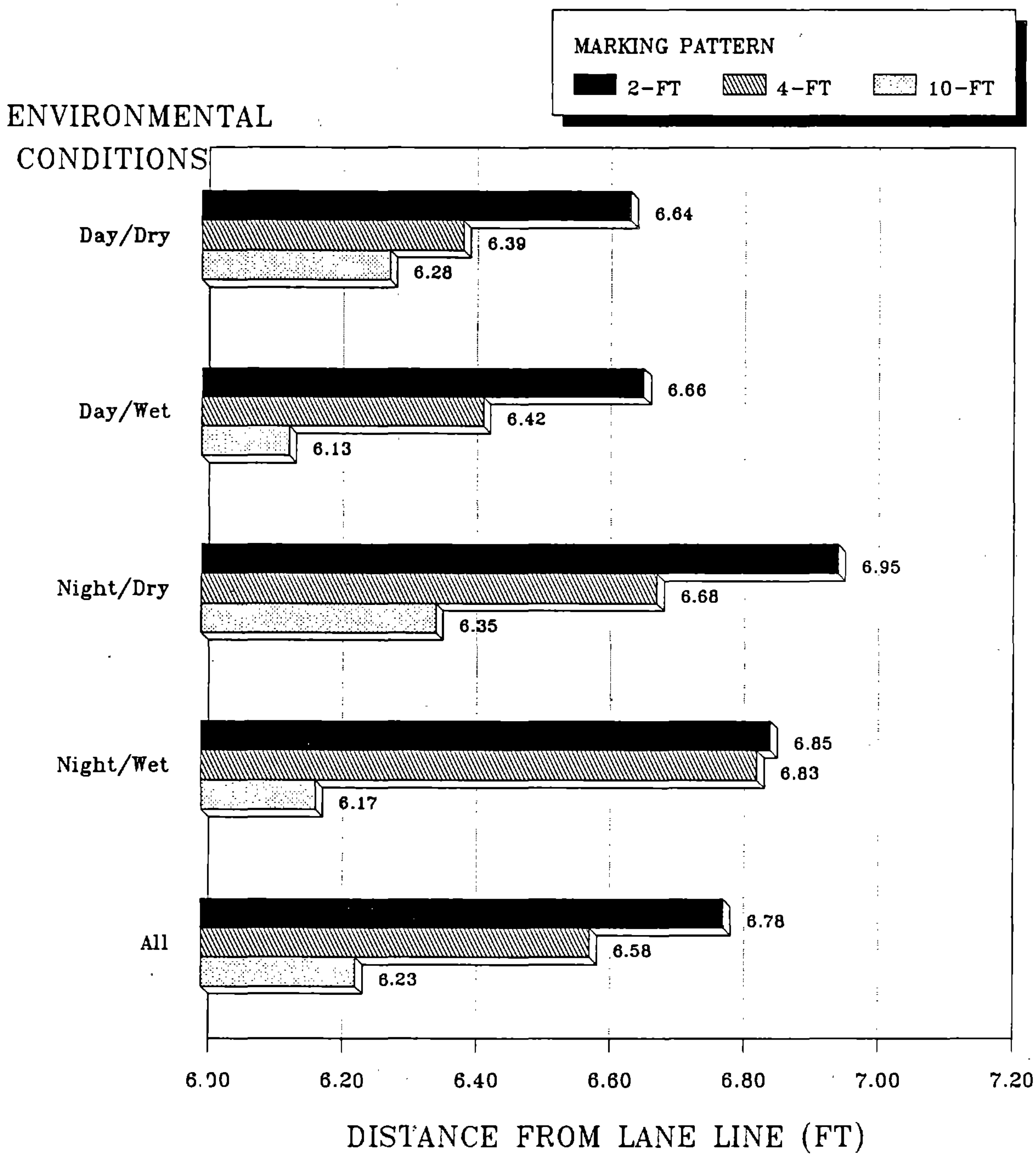
LIGHT	SPEED (mi/h)
Day	67.66
Night	66.71

RAIN	SPEED (mi/h)
Dry	68.03
Moderate	67.21
Intense	63.88

Comparison of Contrasts

Contrast	P-value
2-ft vs. 4-ft	.073
4-ft vs. 10-ft	.184
2-ft vs. 10-ft	.001

[1] Degrees of Freedom
1 ft = 0.305 m; 1 mi/h = 1.61 km/h



1 ft = 0.305 m

Figure 6. Mean distance from the lane line to the center of the vehicle.

The final transformation used in the analysis, which corrected for both problems to an admissable extent, was as follows:

CDIST' = 100/(CDIST x logCDIST)

Using the transformed data, a two-way ANOVA was initially run with marking pattern and environmental condition as class variables. The results, shown in table 8, indicate that marking pattern has a significant effect ($P < 0.001$) on the lateral placement of vehicles in the travel lane. Environmental condition, however, was not a significant factor ($P = 0.311$), and there were no interaction effects among the variables.

Using the Bonferroni multiple comparison method, further analysis of the effects of pavement marking pattern on lateral placement showed the following (*see table 9*):

- Lateral distance from the lane line is significantly less for the 10-ft (3.05-m) marking pattern than for either the 2-ft (0.61-m) or 4-ft (1.22-m) pattern.

- There is no significant difference in the lateral distance from the lane line when comparing the 2-ft (0.61-m) and 4-ft (1.22-m) marking patterns.

ANALYSIS OF LATERAL PLACEMENT VARIANCE

As previously discussed in chapter 4, the lateral placement measure, i.e., distance from the lane line to the outside edge of the left rear tire, was determined at eight points within the roadway segment for each vehicle. An analysis of the variance between these eight measures for each vehicle was undertaken as another

Table 8. ANOVA results for the lateral placement MOE (CDIST') with class variables marking pattern (MARK) and environmental condition (COND).

Significance of Class Variables

Effect	DF[1]	Mean-Square	F-ratio	P-value
COND	3	4.294	1.196	.311
MARK	2	27.608	7.689	.000
COND*MARK	6	2.250	0.627	.709

Means by Factor Levels

MARK	CDIST (ft)
2-ft	6.77
4-ft	6.58
10-ft	6.23

COND	CDIST (ft)
Day/Dry	6.44
Day/Wet	6.40
Night/Dry	6.66
Night/Wet	6.62

[1] Degrees of Freedom

1 ft = 0.305 m

Table 9. Results of Bonferroni multiple comparison method for lateral placement MOE (CDIST′).

Means by Factor Levels		Comparison Results
MARK	CDIST (ft)	
2-ft	6.77	$0.09 \le \beta_{10} - \beta_4 \le 1.07^*$
4-ft	6.58	$0.43 \le \beta_{10} - \beta_2 \le 1.42^*$
10-ft	6.23	$-0.20 \le \beta_4 - \beta_2 \le 0.90$

* Significant with a confidence interval of 96.67 percent.
1 ft = 0.305 m

means of indicating the effectiveness of the different marking patterns. Variances were calculated for each vehicle followed and then analyzed across treatments and conditions.

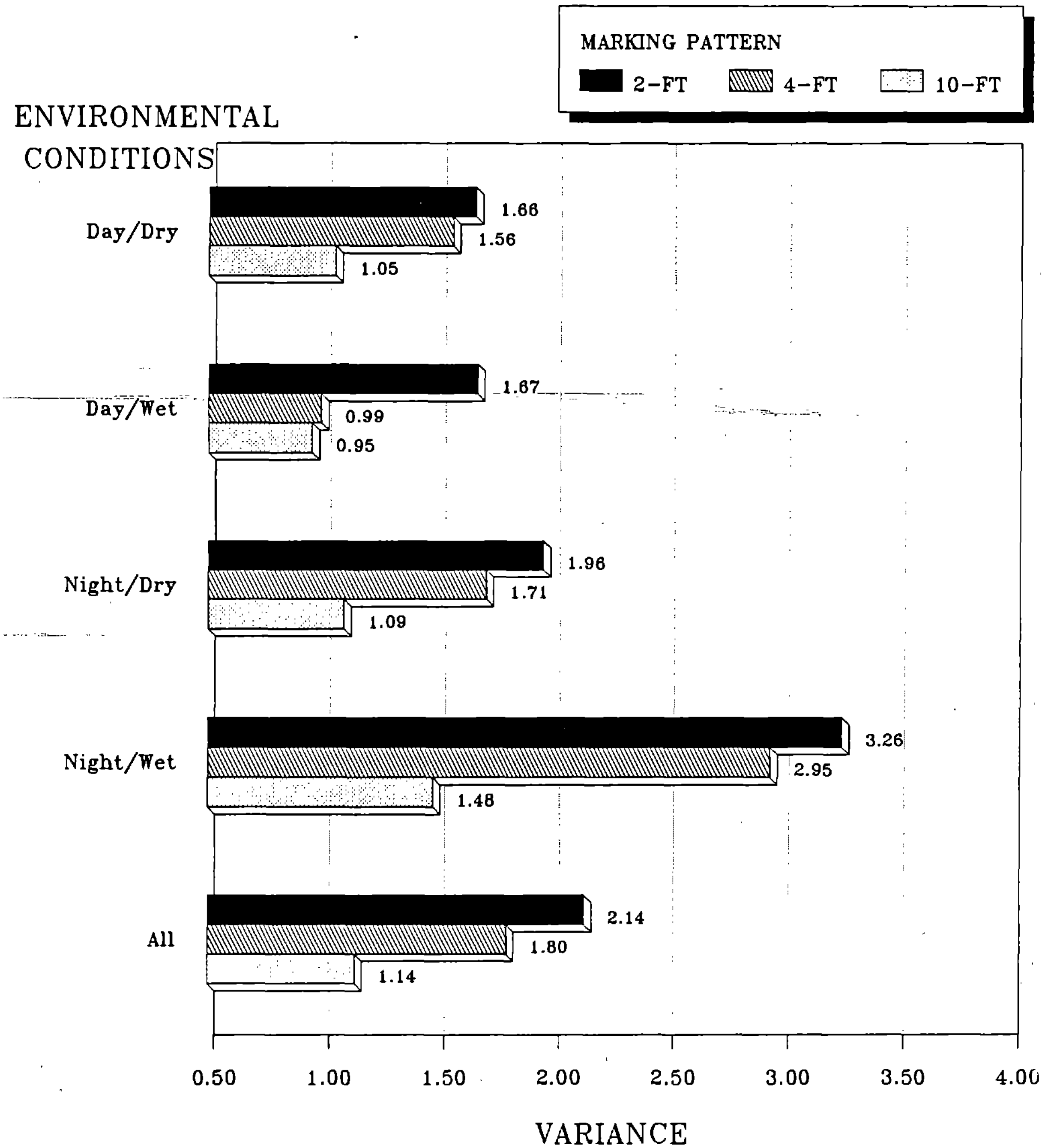
Shown in figure 7 are the means of the lateral placement variances for each marking pattern and environmental condition. A visual inspection of the data shows that the variance increases as the pavement marking decreases in length for every combination of day/night and weather conditions. Statistically, an examination of the data showed the distribution of variances to lack normality. Thus, the nonparametric Kruskal-Wallis test was selected for the analysis (*see appendix C*). The results indicate there is a significant difference ($P < 0.001$) in lateral placement variance that can be attributed to the different marking patterns (*see table 10*).

Additional Kruskal-Wallis tests revealed that significant differences in the lateral placement variance could also be attributed to the light condition (day vs. night) and weather condition (dry vs. wet).

A second visual inspection of the data reveals very small differences associated with day and night under dry weather conditions, which seems to indicate that light condition is not a factor under dry conditions. The differences for dry and wet conditions during the day are also small, which tends to indicate that drivers were able to consistently follow the lane line during the day, regardless of the weather condition. The values for the dry and wet night conditions, however, are very different. These values reveal the problems associated with nighttime driving under wet road conditions. Both the 2-ft (0.61-m) and 4-ft (1.22-m) patterns reflect much greater variance in driver performance when compared to the 10-ft (3.05-m) pattern, which is expected due to the presence of the edgeline in the later case. However, the differences between the 2-ft (0.61-m) and 4-ft (1.22-m) markings are not as widespread.

ANALYSIS OF ENCROACHMENTS AND ERRATIC MANEUVERS

Erratic maneuvers were defined as brake applications and sudden speed and/or directional changes. The data reduction effort identified no sudden speed changes, only one sudden directional change, and six brake applications for all of the



1 ft = 0.305 m

Figure 7. Average lateral placement variance.

Table 10. Results of Kruskal-Wallis test on lane placement variance for the three pavement marking patterns (MARK).

Group	MARK	Count	Rank Sum
1	2-ft	133	33710.0
2	4-ft	123	29830.5
3	10-ft	180	31289.5

Kruskal-Wallis Test Statistic	DF[1]	P-value
38.569	2	< .001

[1] Degrees of Freedom assuming a Chi-square distribution.
1 mi/h = 1.61 km/h

vehicles followed. Due to these small numbers and the corresponding lack of influence on driver performance, no analysis was conducted on this variable.

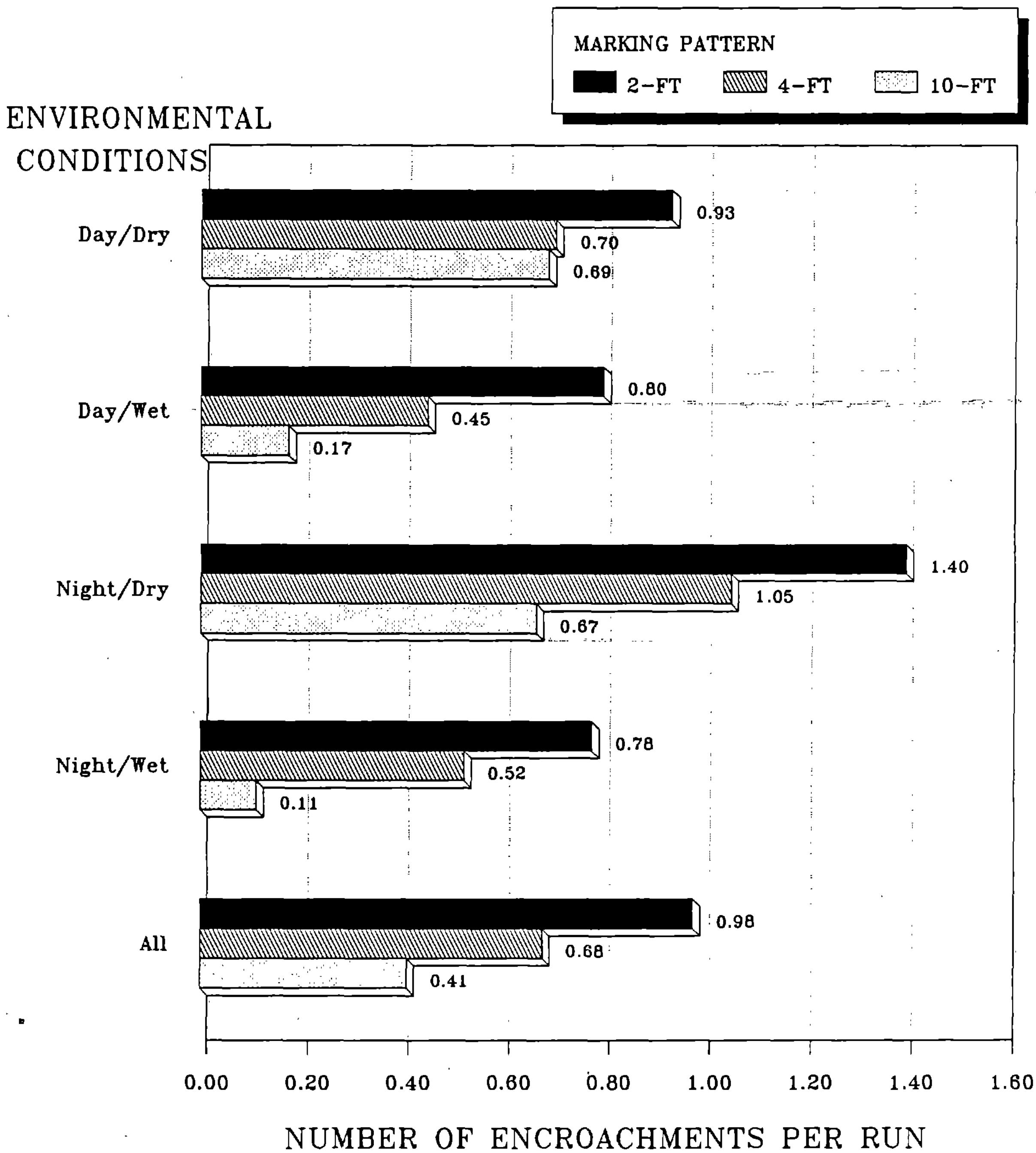
Encroachments, however, occurred more frequently and did produce patterns worthy of analysis. The average number of encroachments (edgeline and lane line) per run are shown in figure 8 and illustrate the trends associated with the marking patterns and environmental conditions.

Shown in table 11 are the observed frequencies of encroachment for each of the pavement marking patterns. Because of the small number of observations in some of the frequency cells, the data were

Table 11. Frequency distribution of encroachments by marking pattern (MARK).

MARK	Number of Encroachments								
	0	1	2	3	4	5	6	7	Total
2-ft	64	32	13	16	5	1	1	1	133
4-ft	70	32	10	6	3	1	1	0	123
10-ft	144	18	8	4	2	4	0	0	180
Total	278	82	31	26	10	6	2	1	436

1 ft = 0.305 m



1 ft = 0.305 m

Figure 8. Average number of encroachments per run.

collapsed into four new cells as shown in table 12. A chi-square analysis of this contingency table yielded a test statistic of 42.48 with 6 degrees of freedom, proving significant differences among the three marking patterns at a confidence level of 95 percent. Similar contingency tables were produced to compare each pair of markings, i.e., 2-ft vs. 4-ft (0.61-m vs. 1.22-m), 2-ft vs. 10-ft (0.61-m vs. 3.05-m), and 4-ft vs. 10-ft (1.22-m vs. 3.05-m). In all cases, there were significant differences in the number of encroachments at the 95 percent confidence level.

A chi-square analysis of the environmental conditions grouped across all three marking patterns was also conducted. The results indicated significant differences in the number of encroachments per run for day versus night and for dry versus wet weather conditions.

Table 12. Collapsed frequency distribution of encroachments by marking pattern (MARK).

MARK	Number of Encroachments				
	0	1-2	3-4	5-7	Total
2-ft	64	45	21	3	133
4-ft	70	42	9	2	123
10-ft	144	26	6	4	180
Total	278	113	36	9	436

1 ft = 0.305 m

CHAPTER 6 - ECONOMIC ASSESSMENT

An assessment of the favorable and unfavorable consequences of using temporary broken-line pavement markings is provided in this chapter. It includes an examination of the cost differences associated with placement of alternative length markings and the incremental benefits obtained by using longer markings. The benefits considered are travel time savings and safety implications of the surrogate accident measures employed in this study, i.e., lateral displacement, encroachments, and erratic maneuvers.

While a thorough cost-effectiveness analysis would ease the decision to use 2-ft, 4-ft, or 10-ft (0.61-m, 1.22-m, or 3.05-m) temporary lane markings during road construction and maintenance operations, this was not possible in this study for two primary reasons:

- The study design did not include collection of accident data since the non-permanent nature of temporary markings precludes finding any clear accident results.

- Cost information for placement of short temporary markings is either not available or highly variable. Several of the nine States contacted, which make use of short temporary markings, do not employ a separate bid item for such costs. Instead, they are included as part of a construction contract's incidental costs. Data that is available shows unit placement costs to vary by several hundred percent.

MARKING TREATMENT ALTERNATIVES

Since the MUTCD requires that non-permanent pavement markings be in place for the shortest time period practicable (normally no longer than 2 weeks), there are two alternative temporary marking treatment scenarios which are candidates for the economic assessment:

- Use of temporary pavement markings during construction operations requiring lane shifts (e.g., to accommodate median crossings) or staged rehabilitation operations (e.g., scarification, oiling, and placement of multiple lifts of pavement). The pavement must be remarked several times during these operations for short time periods, sometimes as short as a day.

- Use of alternative length temporary pavement markings for a period of 7 to 14 days while awaiting the "seasoning" of an asphaltic or chip and seal repavement operation. Past performance of markings placed immediately after these operations indicates a decline in durability, so several States prefer using a short temporary marking for 1 to 2 weeks before installing the required standard MUTCD markings.

These two scenarios only differ in the number of days temporary markings are in place. The critical question then is:

How many days must a standard marking be in place so its benefits offset the difference in costs associated with a short versus a longer temporary marking?

Answering this question begins with a general discussion of the "costs" associated with placement of different length markings. This is followed with an examination of how surrogate measures, in general, and those used in this study can in fact "measure" safety. It concludes with an estimate of the level of safety and other benefits needed to justify use of temporary markings longer than 2-ft (0.61-m).

COSTS FOR ALTERNATIVE MARKING TREATMENTS

Placement Costs

Paint, with and without glass beads, and unremovable and removable retroreflective tape are the materials typically used for temporary markings. Use of the removable tape eases the job of removal prior to placing a final standard pavement marking. Removal is necessary in some cases since many temporary markings are placed on a range of striping intervals (*see table 1 on page 2*) which do not conform to the 40-ft (12.2-m) interval set forth in the MUTCD. Some States also feel it is very difficult to place a standard marking accurately over an existing temporary marking.

Nine States were contacted to determine costs experienced in the placement of short temporary markings. Several had no precise cost information because they employ no separate bid item for this work construction activity. However, three sets of cost data were available; that experienced in placing the pavement markings for the field studies in this research effort and data supplied by the Maryland and Missouri Departments of Transportation (DOT).

In this study, 4-in (10.3-cm) temporary retroreflective paint markings were placed by an experienced pavement marking firm. Their costs included a $475 mobilization fee to move and set up marking equipment at the study site, $125 for an arrow board, and a $0.30 per lineal foot ($0.092 per lineal meter) of paint. This cost structure was based on placing 5,314 lineal feet (1,621 lineal meters) of retroreflective paint markings. The mobilization fee and arrow board charges were experienced each of the two times the equipment was moved to the study site to place the 2-ft and 4-ft (0.61-m and 1.22-m) temporary markings. These charges equated to a total of $0.41 per lineal foot ($0.127 per lineal meter).

Comparative prices supplied by the aforementioned DOT's show the mean placement costs per lineal foot (0.305 m) of temporary marking material are as follows:

	Maryland	Missouri
Paint	$0.77	-
Striping Tape	$1.40	-
Removable Tape	$1.47	$1.73

Maryland's cost figures are based on a regression analysis of unit costs for 1991 construction projects. Although there was a wide range of unit costs (e.g., $0.20 to $1.40 for the paint and $0.01 to $2.50 for the striping tape) by project, the regression analysis showed quantity of markings to be put down had practically zero effect on the unit price.

The data for Missouri is a 1990 statewide average unit bid price for white preformed non-permanent marking tape. Average costs for placing similar yellow tape was $1.81 per lineal foot ($0.55 per lineal meter) of tape. Since the largest and most recent cost data available is that supplied by Maryland DOT, their cost values have been used in the economic assessment made at the end of this chapter.

User Costs

Some past evaluations of alternative width edgelines have included nonaccident user costs (e.g., time delays incurred by drivers while the stripes are being placed) in their cost-effectiveness analysis.[6] Their use in these type studies is reasonable because the comparisons being performed involved doing nothing versus restriping an edgeline.

Nonaccident user costs are not considered reasonable during placement of the non-permanent pavement markings since both scenarios require work personnel and equipment to be present. Although extra effort may be required in placing the longer markings its incremental effect is likely small. The markings are normally being placed during a construction activity with reduced posted speed limits. This fact, coupled with the short distance any driver would be impeded by a temporary marking operation, negates the importance of such a cost in this assessment.

However, once the temporary markings are in place, time benefits or disbenefits could result from the use of one type marking versus another. Previous studies and this study have shown pavement markings to have an effect on drivers' average running speeds. Accordingly, the economic value of this speed change is reflected in a later part of this analysis.

Incremental accident costs incurred by society as a direct result of using alternative marking treatments are also important. As noted earlier, the scope of this study and the experimental design employed in the field studies prevented collection of accident cost data for use in this economic assessment. However, the four MOE's collected in the field studies to measure driver performance provide decision makers with useful information about the "safety" consequences of employing short temporary pavement markings. The following section provides evidence that these MOE's are truly surrogate "safety" measures.

SURROGATE SAFETY MEASURES

Datta et al. investigated the feasibility of using surrogate measures in highway safety analysis where an accident surrogate measure was defined as a quantifiable observation which could be used in place of or as a supplement to accident records.[7] This examination involved many activities which included obtaining judgments from a group of highway safety experts on promising variables which could be mathematically related to accidents. These experts concluded that vehicle speed, lateral placement, and erratic maneuvers were strong safety surrogates.

These surrogates have subsequently been employed in many safety evaluations. Bowman and Brinkman employed both speed and lateral placement as safety performance measures in evaluating low-cost accident countermeasures, including pavement markings, at narrow-bridges. These researchers felt pavement markings are intended to increase visual conspicuity and driver information. Therefore, the markings should result in more uniform speeds and vehicle paths. They concluded that: 1) lateral placement further away from a hazard indicates a potential for accident reduction, and 2) consistent deviations in the lateral placement along a study site signifies a more uniform vehicle path and hence an increase in motorist guidance.[8]

Hughes et al. also employed lateral placement (i.e., departures from the travel lane) as an indication of the effectiveness of an edgeline. The conclusions showed such lines to have a positive influence on reducing edgeline and centerline encroachments, but accident effects were mixed.[6]

Shepard also used vehicle speed and vehicle placement relative to the lane line to evaluate closely spaced raised pavement markers as a supplement to existing pavement markings. Despite the fact all data were collected under dry, nighttime conditions, he found a higher percentage of vehicles traveling in the center of the lane and with fewer encroachments over the centerline in the presence of the supplemental RPM's.[9]

Thomas and Taylor also used vehicle placement as a safety surrogate measure to determine the nighttime effect of pavement edge striping. This study, which was performed on 4-lane divided highways with 12-ft (3.66-m) lanes, revealed that pavement markings can cause drivers to move their vehicles laterally in the lane by 12 to 18 in (30 to 46 cm).[10]

Williston, who observed the transverse placement of vehicles at night in the presence of the centerline before and after edge markings had been installed, found drivers tend to position their vehicles more centrally in the fully marked lane, i.e., with edgelines, and to operate at faster nighttime speeds. The latter was attributed to drivers' greater confidence of knowing where their vehicles are on the road.[11]

Two additional rural two-lane studies, one by Basile and one by Musick, evaluated the accident effects of edgelines. Both researchers found roughly 50 percent reductions in accidents at access points. However, there are marked differences between the two studies when considering wet pavement and nighttime conditions. Whereas Basile's Kansas study showed a 42 percent increase in nighttime accidents and no change under wet weather conditions, Musick's Ohio study found 35 and 12 percent reductions, respectively.[12,13] Similar conflicting accident findings were found between States in the large accident evaluation of alternative width edgelines conducted by Hughes et al.[6]

Despite these mixed accident findings and the fact that most of the studies were evaluating edgelines (none under both adverse light and weather conditions) as compared to centerlines, nearly every researcher pointed out: 1) the importance of providing drivers with a pavement marking on which to guide their vehicle path, and 2) there is a positive relationship between the number of markings present and the ability of a driver to operate a vehicle. This is also confirmed in studies where drivers have had to subjectively evaluate alternative marking treatments. For example, in the study by Dudek et al., subjects stated a preference for longer markings.[4]

In summary, most pavement marking evaluations have shown that drivers do react positively to the markings by better centering of their vehicles in the travel lane, by increasing their running speed (which is theorized to suggest markings provide more positive guidance), and by having fewer encroachments on either the centerline, lane line, or edgeline. Unfortunately, good accident/pavement marking relationships have eluded all past research efforts.

COST-EFFECTIVENESS ANALYSIS

Since no mathematical relationships exist to place a monetary value on the "safety" surrogates used in this study, the following economic analysis calculates the amount of accident reduction needed to equate incremental costs in utilizing 2-ft, 4-ft, or 10-ft (0.61-m, 1.22-m, or 3.05-m) temporary pavement markings. These values are then examined, by looking at typical freeway accident rates and the "safety" surrogate values, to determine if they could reasonably be attained.

Incremental Costs and Benefits

Table 13 presents the incremental pavement marking placement costs and travel time benefits for temporary 2-ft (0.61-m) markings versus either 4-ft (1.22-m) or 10-ft (3.05-m) markings. Both the costs and benefits are per lineal mile of roadway in one direction of a four-lane freeway (i.e., it assumes only one lane line must be temporarily marked). The benefits are based on a 1-way traffic flow of 1,000 vehicles per day and with the temporary markings in place for a single day.

The additional pavement marking costs, which would be incurred by using either of the longer temporary markings, must be offset by either 1) travel time savings produced by a combination of average

Table 13. Costs and benefits of alternative temporary pavement markings.

	Pavement Marking Comparison		
Incremental Costs	4 ft vs 2 ft	10 ft vs 4 ft	10 ft vs 2 ft
Placement of Temporary Pavement Markings per lineal mile.[1]			
a. Removable Tape	$388	$1,164	$1,502
b. Striping Tape	370	1,110	1,480
c. Paint	203	609	812
Incremental Benefits			
Road User Travel Time Saved per 1,000 vehicles per day per lineal mile of a pavement marking project.[2]	$3.72	$2.16	$5.88

[1] Based on 132 40-ft intervals in 1 mi. Average project lengths in Maryland were 2.8 mi, 2.3 mi, and 1.0 mi when removable tape, striping tape, and paint, respectively, were used for non-permanent lane markings.[14]

[2] Based on increased running speed (see figure 9) and a value of time equal to $13.16 per vehicle hour (Chui and McFarland's 1985 suggested rate for automobiles updated to a 1991 value assuming 4 percent inflation.[15]

1 ft = 0.305 m

daily traffic (ADT), length of marking project, and the number of days the temporary markings would be in place and/or 2) the "improved" marking would reduce a sufficient number of accidents to offset any incremental costs not offset by road user travel time savings.

In the first case, a 1-way ADT of 20,000 on a 2.8-mi (4.5-km) marking project where a 4-ft (1.22-m) temporary removable tape is in place for 6 days would produce a time savings benefit of $1,250 ($3.72 x 20,000 ADT/1,000 x 2.8 mi x 6 days). This would offset the $1,086 ($388/mi x 2.8 mi) cost to move from a 2-ft (0.61-m) to a 4-ft (1.22-m) temporary marking. However, the time benefits would not offset the costs to move to a 10-ft (0.305-m) marking.

If accident benefits are also needed to offset increased placement costs for a longer temporary marking, then the information presented next could be utilized in examining the safety potential of longer temporary pavement markings.

Accident Reductions

There are two choices for determining the accident reduction which might be obtained by using longer temporary markings. First, one could use a percentage reduction factor from a list of reduction factors based on a summary of research studies performed throughout the United States. This list, which many States use, (e.g., North Carolina and California) suggests that installation of striping and/or delineators reduces total accidents by 18.9 percent. The same list also indicates that right edgelines reduce total accidents by 2.0 percent.[16]

Because of this large percentage difference, one could expect centerlines and lane lines to provide significant safety benefits. Wattleworth et al. indicate there is a 5 percent reduction in total accident costs from using full centerline marking but is silent on the benefit of lanelines.[16]

Since lane lines, in the absence of edgelines, must be used by a driver to prevent encroaching into an adjacent lane or leaving the road, one could conservatively expect the safety benefit of a lane line to be positive but to not exceed the 5 percent identified above. Based on this information, it would appear that moving from a 2-ft (0.61-m) to a 10-ft (3.05-m) marking can be conservatively estimated to reduce total accident costs by 1 percent. At a typical urban freeway accident rate of 1.94 accidents per 1-million vehicle miles, this represents a savings of 0.0000053 accidents per day, per mile, per 1,000 ADT.

An alternative approach is a more detailed examination of the effects of lane lines and edgelines on encroachments across the markings and their safety benefits. A vehicle encroaching a lane line provides opportunity for it to be involved in a sideswipe collision, and when crossing an edgeline, a vehicle is subject to all types of rollover and fixed object collisions. McFarland and Rollins suggest use of the following encroachment-accident probability models where the 2-way ADT is 6,000 or greater:

$$Rm = 0.00026645 \times ADT/2$$

$$Rr = 0.00014961 \times ADT/2$$

where Rm and Rr are the potential accident producing encroachment rates per mile per year in one direction onto a freeway's median and right-side, respectively. Encroachments were defined as vehicles leaving the roadway.[15] Therefore, if there are 1,000 vehicles traveling in one direction on a freeway per day (this equals ADT/2 in the formulas), then the accident potential for median and right-side encroachments is 0.00114 accidents per mile per day.

In this current research, encroachments were generally found to be reduced by 30 percent regardless of the light or weather condition when moving from a 2-ft (0.61-m) to a 4-ft (1.22-m) marking and an additional 30 percent when moving to a 10-ft (3.05-m) marking. However, these percent reductions apply to crossings of lane lines and edgelines, rather than departures from the sealed road surface.

Because this encroachment definition differs from that used by McFarland and Rollins, it is recommended that this benefit assessment should be based on an estimate of how many accidents must be prevented, through use of a longer temporary lane line markings, to offset costs not covered by travel time savings. Then, a decision maker must decide if the reduction in edgeline and lane line encroachments and other driver performance measure improvements produced by a longer marking is likely to achieve the calculated required accident reduction. Following is an example of the required accident reduction calculation.

In the example discussed earlier, it was noted that time savings alone would not offset the costs to move from a 2-ft (0.61m) removable tape marking to a similar 10-ft (3.05-m) marking. That is, the travel time benefits of $1,976 ($5.88 x 20,000 ADT/1,000 x 6 days x 2.8 mi) would not offset the $4,206 ($1,502/mi x 2.8 mi) additional marking placement cost. Therefore, accident reduction must make up the $2,230 difference.

We can now make use of the previous information to assess the safety benefits. If AASHTO's conservative $20,000 average run-off-the road accident cost is used in lieu of FHWA's 1986 $45,000 value, then, 0.1115 accidents must be prevented by the longer pavement marking.[17,18] McFarland and Rollins' models indicate 0.00114 accidents would occur per mile per day per 1,000 ADT one-way. In the cited example, this would equate to 0.383 accidents (0.00114 accidents/mi/day x 2.8 mi x 6 days x 20,000 vehicles/1,000 vehicles).

Using the preceding calculations, there must be a 29.1 percent (0.1115/0.383) or better chance that the longer marking will prevent an accident. Since this research showed a roughly 60 percent reduction in edgeline and lane line encroachments in moving from a 2-ft (0.61-m) to a 10-ft (3.05-m) temporary marking, the odds seem favorable such an accident reduction would occur. However, the benefit/cost value is not likely to be much greater than one.

CHAPTER 7 - SUMMARY AND CONCLUSIONS

SUMMARY OF RESULTS

The primary issue addressed in this study was:

What effect does pavement marking pattern have on driver performance?

A summary of the results from the analysis indicated the following:

- There were significant differences between the average running speeds of vehicles when comparing the 10-ft (3.05-m) marking pattern to the 2-ft pattern. There were no significant differences in speeds when comparing the 4-ft (1.22-m) marking pattern to either the 10-ft (3.05-m) or the 2-ft (0.61-m) pattern. Overall, travel speeds were reduced as the length of the marking became shorter (*see figure 9*).

- The lateral placement MOE, distance from the lane line to the central axis of the vehicle proved to be significantly different for the 10-ft (3.05-m) marking pattern when compared to either the 2-ft (0.61-m) or 4-ft (1.22-m) pattern. The differences for the 2-ft vs. 4-ft (0.61-m vs. 1.22-m) patterns, however, were not significantly different. The general trend was for drivers to position their vehicles closer to the center of the lane, i.e., 6 ft (1.83 m) from the lane line, as the length of the marking was increased (*see figure 9*).

- Lane placement variance, which served as a measure of a driver's ability to traverse the roadway in a consistent manner, proved to be significantly different for the three marking patterns. The results indicated an increase in lane placement variability as the length of the marking was reduced (*see figure 9*).

- The differences between the average number of edgeline and lane line encroachments for the three marking patterns were significantly different and revealed that drivers tended to stray out of the travel lane more frequently as the marking was reduced in length (*see figure 9*).

In addressing the primary issue above, the data collection and analyses were structured to determine the effects of marking pattern with respect to two secondary issues: day versus night and weather conditions. Provided below is a summary of the results from the analysis as related to these issues.

What effect does day versus night, have on vehicle operations with respect to pavement marking pattern?

- While the data showed speeds to be generally lower at night than in the day, there were no significant differences between the three marking patterns that could be attributed to time of day.

- Drivers positioned their vehicles closer to the center of the lane during the day than at night for all three marking patterns. However, these differences proved to be insignificant with respect to the length of the marking.

- The variance in lane placement was proven to be significantly greater for night conditions. The results indicated that the differences in variance between day and night for the 10-ft (3.05-m) pattern was relatively small compared to the 2-ft

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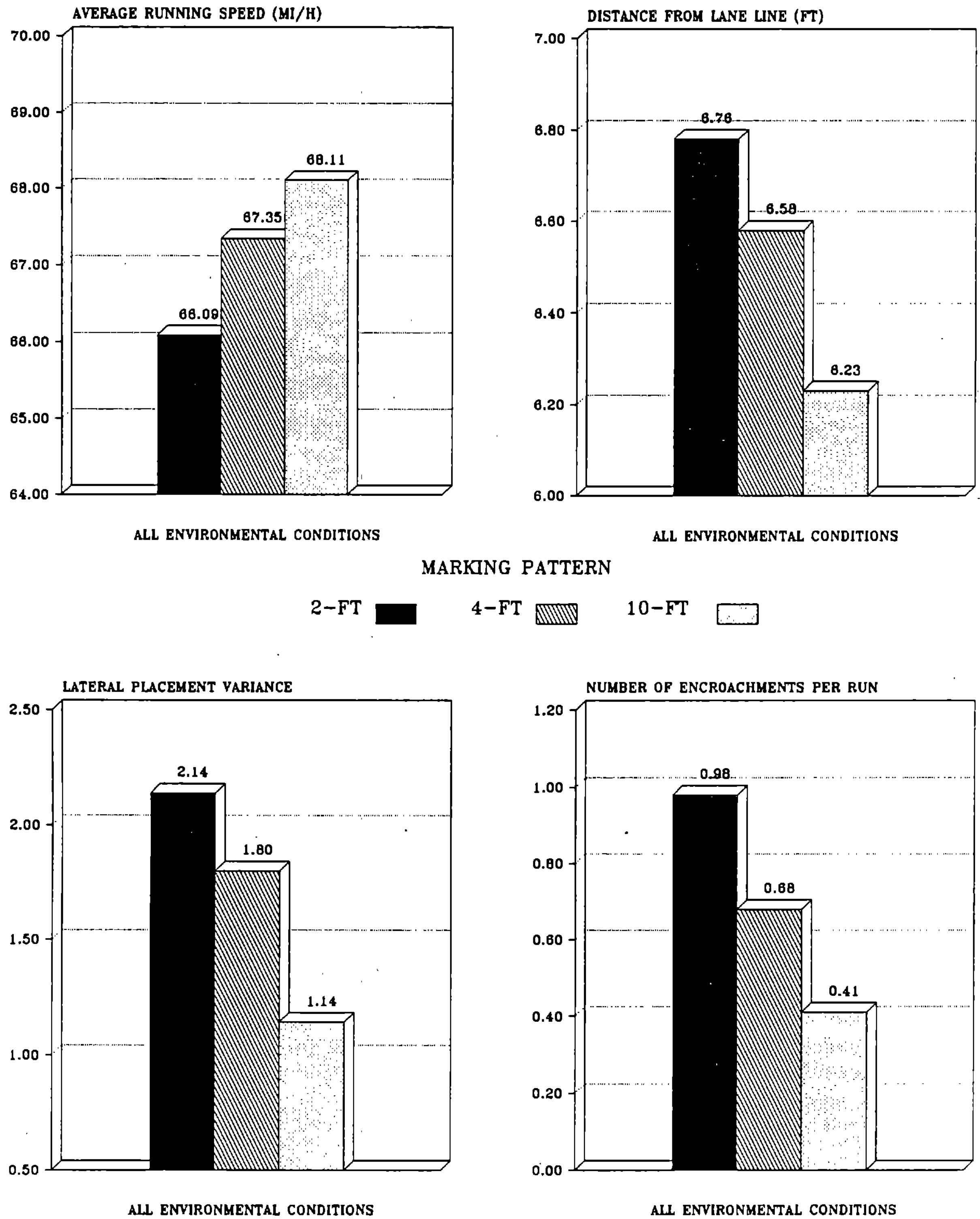


1 ft = 0.305 m; 1 mi/h = 1.61 km/h

Figure 9. Summary of operational measures across all environmental conditions.

(0.61-m) and 4-ft (1.22-m) patterns. It should also be noted that the differences in variance between day and night for the 2-ft (0.61-m) and 4-ft (1.22-m) patterns was relatively the same.

- The number of encroachments per run during the night were significantly different from the number which occurred during the day. The results revealed higher values at night for each marking pattern.

What effect does adverse weather, i.e., rain and wet road conditions, have on driver performance with respect to pavement marking pattern?

- The effects of weather, specifically rain, on the differences in average running speeds between the three marking patterns were mixed. There were significant differences between the 10-ft (3.05-m) and 2-ft (0.61-m) patterns. There were no significant differences between the 10-ft (3.05-m) and 4-ft (1.22-m) patterns. Finally, the differences in speeds between the 2-ft (0.61-m) and 4-ft (1.22-m) patterns were not significant, but did reveal some effects that could be attributed to weather conditions. Generally, speeds were lower for wet weather conditions compared to dry conditions for each marking pattern.

- The effects of weather on the differences in lateral placement, i.e., the ability of a driver to center their vehicle in the travel lane, between the three marking patterns were proven to be insignificant. There was no consistent pattern for this measure when examining wet and dry conditions and the actual differences were relatively small.

- The impact of weather on lane placement variance did prove to be significant. This confirmed earlier results which showed lane placement variability to increase as the length of the marking decreased and emphasized the impact of rain on this measure.

- The number of encroachments per run were significantly different for dry and wet weather conditions. The data revealed a slight decrease in the number as a result of wet weather conditions.

CONCLUSIONS

For each operational measure examined, the 10-ft (0.305-m) marking pattern generally resulted in better driver performance than either the 2-ft (0.61-m) or 4-ft (1.22-m) pattern. This result is reasonable since the 10-ft (0.305-m) pattern consisted not only of longer stripes, but also contained edgelines, which is the standard full complement of markings recommended in the MUTCD.

Comparisons against this scenario did provide indications of the differences to be expected when drivers encounter nonstandard markings. For example, based on data in this study, drivers would travel 0.76 mi/h (1.22 km/h) slower on a segment with 4-ft (1.22-m) stripes and 2.02 mi/h (3.25 km/h) slower on a segment with 2-ft (0.61-m) stripes than they would on the same roadway segment fully marked.

The differences are even more significant when examining encroachments. Compared to the 10-ft (0.305-m) pattern, drivers are likely to encroach over the lane line or edgeline 66 percent more in the presence of a 4-ft (1.22-m) temporary marking and 139 percent more in the presence of a 2-ft (0.61-m) marking. These values increase dramatically under night and wet weather conditions.

Overall, the results provide evidence of significant decreases in driver performance associated with either of the temporary marking patterns tested. While it is not practical to place full markings on a temporary basis, measures should be taken to prevent reductions in driver performance which result in increased accident potential. Such measures include the use of longer temporary markings and the appropriate use of advance warning signs to indicate a change in the pavement marking pattern.

While the comparison of operational measures for the 2-ft (0.61-m) versus 4-ft (1.22-m) marking patterns did not result in a large number of statistical differences, largely due to the small sample size, there were certain trends that existed with respect to driver performance:

- The speed at which drivers traveled decreased as the length of the lane line decreased.

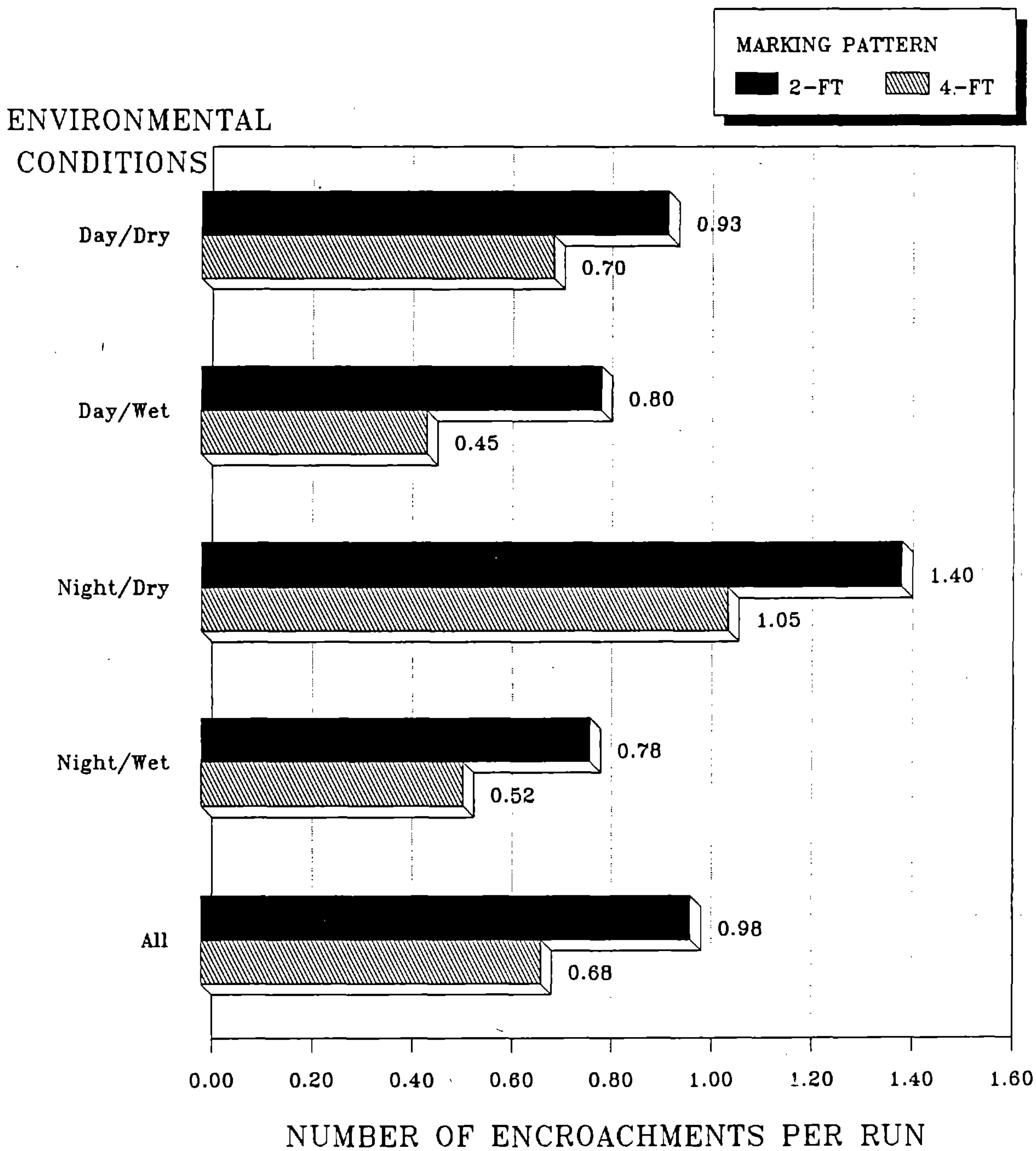
- Drivers positioned their vehicles closer to the center of the lane as the length of the lane line increased.

- The variability of vehicle placement within the lane increased as the length of the lane line decreased.

- The number of encroachments increased as the length of the lane line decreased.

- All operational measures were negatively impacted by adverse weather conditions.

Overall, drivers performed better with the 4-ft (1.22-m) stripes compared to the 2-ft (0.61-m) stripes. The number of encroachments per run is an operational measure which illustrates the differences in the two marking patterns (*see figure 10*). Under dry weather conditions, day and night, the number of encroachments is 33 percent higher for the 2-ft (0.61-m) pattern compared to the 4-ft (1.22-m) pattern. This value increases to 50 percent for nighttime/wet weather conditions and 77 percent for daytime/wet weather conditions.



1 ft = 0.305 m

Figure 10. Number of encroachments per run for the 2-ft and 4-ft marking patterns.

APPENDIX A - CURRENT NON-PERMANENT PAVEMENT MARKING POLICY

The current FHWA policy on non-permanent and permanent pavement markings is illustrated in figures 11, 12, and 13. The following notes serve as supplemental information to the figures:

- Low volume highways should be defined in accord with Statewide policy as approved by the FHWA Division Office.

- Signs may be used in lieu of pavement markings on low volume roads, after which permanent markings should be installed.

- On other than low volume highways, short-term or permanent markings should be in place before the highway is opened to traffic.

- Edgelines are required after 14 days on all Interstate and rural multilane highways and on other highways after 14 days when State policy calls for the use of edgelines.

This policy is reflected in Section 6D of the MUTCD (*see figure 14*). The changes in the policy are noted by the ruling numbers VI-3, which included the

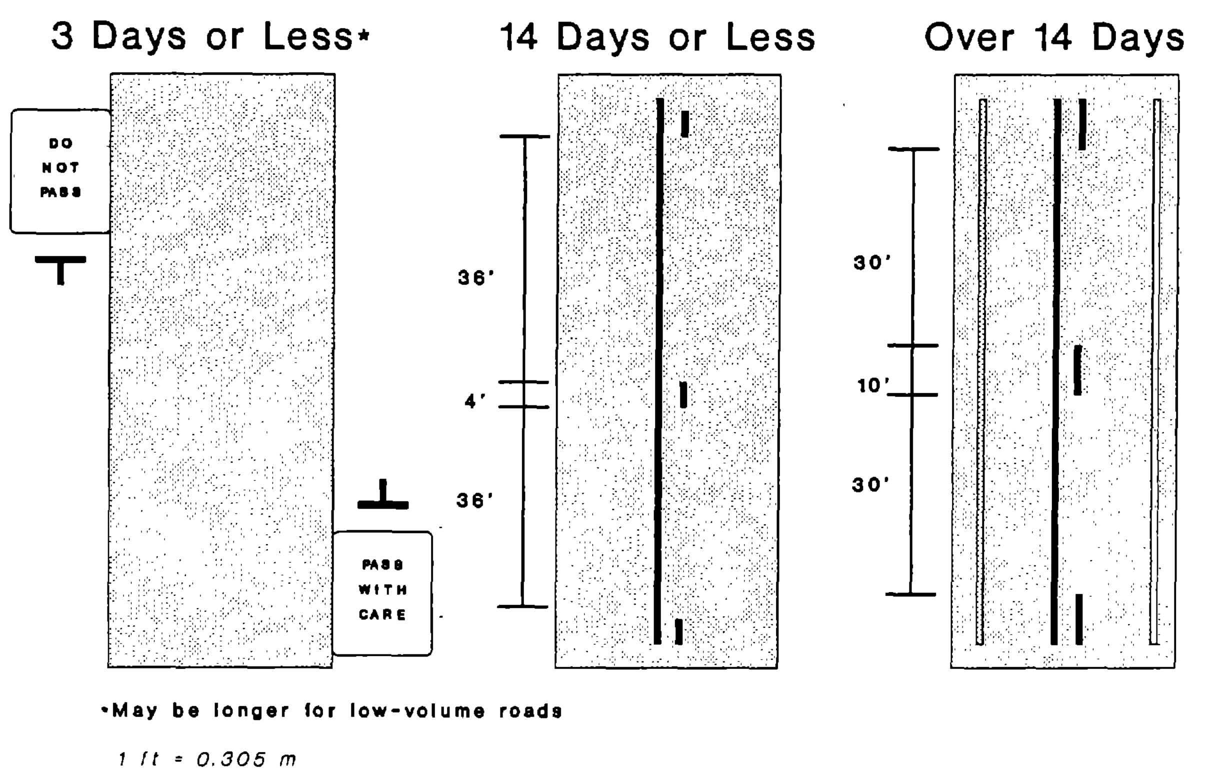


Figure 11. FHWA pavement marking policy for undivided two-lane or three-lane highways.

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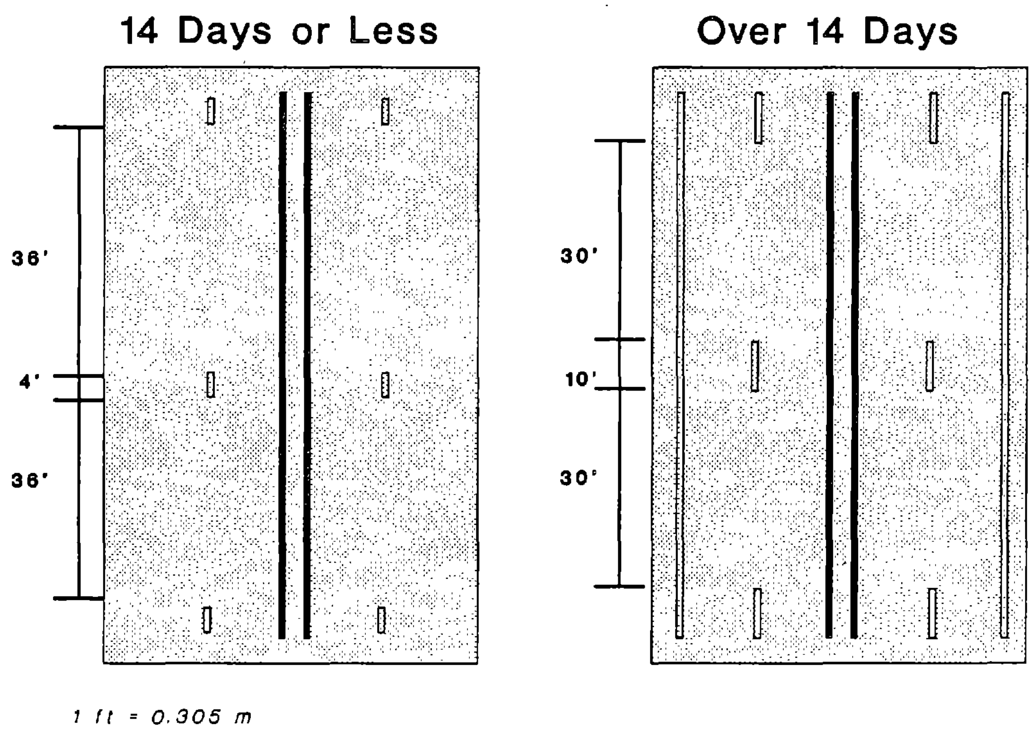

Figure 12. FHWA pavement marking policy for undivided multilane highways.

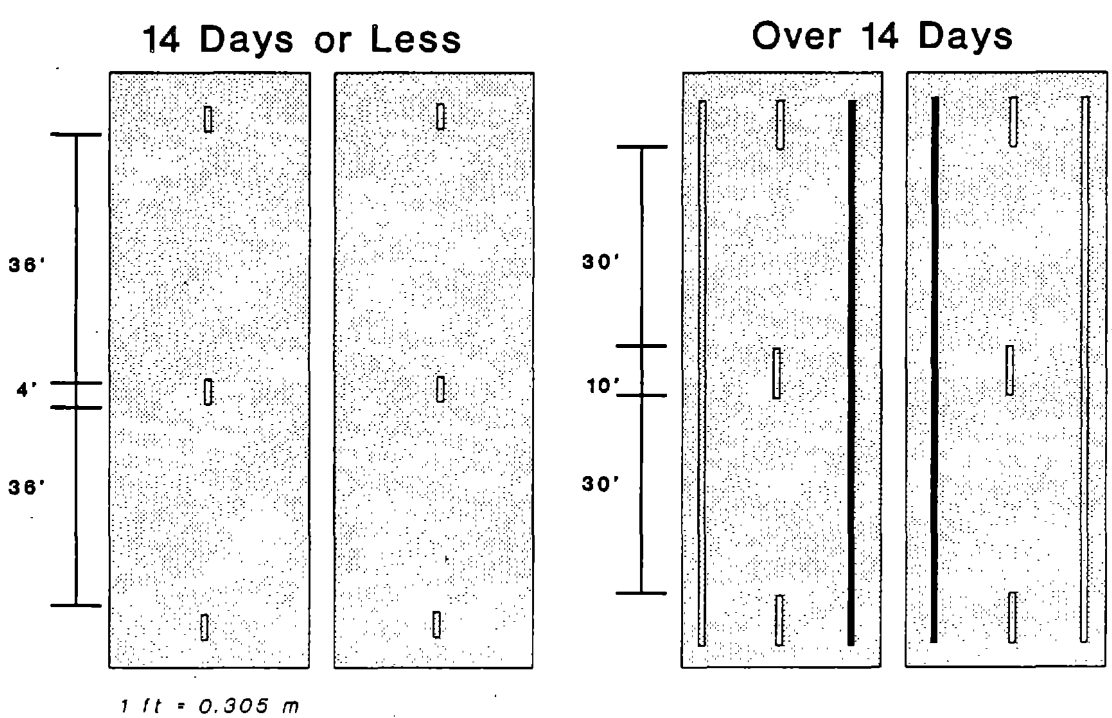

Figure 13. FHWA pavement marking policy for divided multilane highways.

D. MARKINGS

6D-1 Pavement Marking Applications

When construction work necessitates the use of vehicle paths other than the lanes normally used, daytime and nighttime drive-through checks should be made to evaluate the path and the possibility that the pavement markings might inadvertently lead drivers from the intended path. Markings no longer applicable that might create confusion in the minds of vehicle operators and pedestrians shall be removed or obliterated as soon as practicable. Where staged construction requires changes in barricades or channelization, similar day-night checks and evaluations of the existing pavement marking should accompany each change. Inappropriate existing pavement markings should be removed and the new delineation placed before opening the affected lane or lanes to traffic. Traffic shifts from one path to another should not be attempted unless there is sufficient time, equipment, materials, and personnel available to properly complete them before the end of the workday. VI-57(c) Rev. 5

Conflicting pavement markings shall be obliterated to prevent confusion to vehicle operators. Proper pavement marking obliteration leaves a minimum of pavement scars and completely removes old pavement paint. Painting over existing stripes does not meet the requirements of removal or obliteration. The intended vehicle path should be clearly defined during day, night, and twilight periods under both wet and dry pavement conditions. VI-57(c) Rev. 5

Before any new highway or portion of a highway while under construction is opened to traffic, all markings required by Section 6D-3 should be in place. All necessary markings should be in place along its approaches to and throughout the length of any surfaced detour or temporary roadway before such detour or roadway is opened to traffic. For surfacing operation where pavement markings are important to the definitions of lanes and to the guiding of traffic along the path of the roadway, temporary pavement markings should be installed before nightfall. VI-3(c) VI-57(c) Rev. 5

Permanent markings, in accordance with MUTCD Sections 3B, 7C, 8B-4, and 9C, shall be installed on permanent pavement surfaces and final lifts where applicable as soon as practicable. Also, pavement markings in accordance with MUTCD Sections 3B, 7C, 8B-4, and 9C, shall be used on temporary pavements, detours, runarounds, or interim lifts open to traffic and where the project work is suspended for the winter or other extended periods of time. VI-57(c) Rev. 5

For short-term operations it is often impractical to provide relocated painted pavement markings due to the time required and the expense VI-57(c) Rev. 5

Figure 14. Section 6D of the Manual on Uniform Traffic Control Devices.[2]

involved in removing the original and/or the relocated pavement markings. Many short-term operations can be adequately marked with pressure sensitive traffic marking tape or temporary raised pavement markers. Either of these types can be applied simply and quickly and can be removed with little or no difficulty when changing traffic patterns make the installation obsolete. VI-57(c) Rev. 5

Where maintenance activities are being performed, the use of pavement markings generally has little application. Normal maintenance work is considered to be that type of work that would be accomplished within one or more continuous work shifts with the worksite being protected by an adequate complement of warning signs, flaggers, and channelizing devices to indicate the proper vehicle path. Longer-term maintenance work should, for the purpose of traffic-handling through the worksite, be treated as a "construction" project.

6D-2 Delineators

Delineation in construction and maintenance zones is intended to be a guide to indicate the alignment of the roadway and to outline the required vehicle path through these areas. Delineators are not to be used as warning devices.

Delineators are retroreflective units capable of clearly reflecting light under normal atmospheric conditions from a distance from a distance of 1000 feet when illuminated by the upper beam of standard automobile lights. Reflective elements for delineators shall have a minimum dimension of approximately 3 inches.

Delineator applications in construction and maintenance areas should always be made in combination with some of the other traffic control devices discussed in Part VI-C.

Delineators, when used, shall be mounted on suitable supports so that the reflecting unit is about 4 feet above the near roadway edge. The standard color for delineators used along the right side of streets and highways shall be white. The color of delineators used along the left edge of divided streets and highways and one-way roadways shall be yellow. Spacing along roadway curves should be such that several delineators are always visible to the driver.

6D-3 Short-Term Markings

Short-term pavement markings are those that may be used until the earliest date when it is practical and possible to install pavement markings that meet the full MUTCD standards for pavement markings. Normally it should not be necessary to leave short-term pavement markings in place for more than two weeks. All short-term pavement markings, including pavement markings for no-passing zones, shall conform to the requirements of Sections 3A and 3B with the following exceptions: VI-3(c) VI-57(c) Rev. 5

Figure 14. Section 6D of the Manual on Uniform Traffic Control Devices (continued).[2]

1. All short-term broken line pavement markings shall use the same cycle length as permanent markings and be at least four feet long, except that, half cycle lengths with a minimum of 2-foot stripes may be used for roadways with severe curvature. (See Section 3A-6). This applies to white lane lines for traffic moving in the same direction and yellow center lines for two-lane two-way roadways when it is safe to pass.

2. For those short-term situations of 3 calendar days or less for a two or three lane road, no-passing zones may be identified by using signs rather than pavement markings (See Sections 3B-4, 3B-5, and 3B-6). Also, signs may be used in lieu of pavement markings on low-volume roads for longer periods, when this practice is in keeping with the State's or highway agency's policy. These signs should be placed in accordance with Section 2B-21. VI-3(c) VI-57(c) Rev. 5

3. The short-term use of standard school zone, railroad, stop line, and other pavement markings should be in keeping with the State's or highway agency's policy. (See Section 3B-6).

4. Short-term edgelines are not required on Interstate and other highways previously marked with edgelines when in keeping with the State's or highway agency's policy. (See Section 3B-6).

5. Raised pavement markers may be used as vehicle positioning guides, as supplements to, or as substitutes for pavement markings (see Sections 3B-14, 3B-15, and 3B-16). All raised pavement markers when used to substitute for pavement markings in work zones shall be retroreflective, shall be the same color as the pavement markers for which they are substituted, and shall be visible during the daytime.

Each highway agency should develop a policy that will , within the scope of this Section, provide more detailed criteria and describe the conditions where temporary pavement markings will be used. This policy should include, but not be limited to, criteria, definitions of extended periods of time, and traffic volume thresholds for low-volume roads.

Figure 14. Section 6D of the Manual on Uniform Traffic Control Devices (continued).[2]

addition of Section 6D-3, and VI-57 which state the following:

VI-3: "Provides for safe traffic operations in construction and maintenance zones through the required use of uniform temporary pavement markings and other traffic control devices."[2]

VI-57: "Provides more guidance for pavement markings on permanent and short-term pavement surfaces, allows flexibility for the use of signs rather than pavement markings for low-volume roads, and recommends that State highway agencies develop a policy within the scope of this section, for using short-term pavement markings."[2]

Both of these rulings contained a compliance date of December 31, 1988.

APPENDIX B - DATA COLLECTION AND REDUCTION FORMS.

Contained in this appendix are examples of the forms used during the data collection and reduction tasks of this study. Each form shown has been partially completed to illustrate the type of information actually recorded. Figure 15 is the data collection form used by the field crew to record information about the vehicles being followed. Also recorded on this form were the environmental conditions, i.e., light condition (day versus night), weather condition, and rain intensity.

Figure 16 is the data reduction form used for recording encroachments. As indicated on the form the location and the length (in distance and time) of each event were recorded. The erratic maneuvers, including brake applications, sudden speed changes and sudden directional changes were recorded on a form like the one shown in figure 17. Finally, the lateral placement data obtained from the video images were recorded on forms like the one shown in figure 18. This form included the information necessary for computing vehicle width and the corresponding lateral placement at each measurement point.

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IN-VEHICLE DATA COLLECTION FORM

Light Condition(D/N)__________ Weather(D/W)__________
Marking Type(2/4/10)__________ Date__________
RAIN (R) = W/S/L/M/H

Time	Run	Tape	Watch	R	Vehicle Description

Figure 15. Field data collection form.

ENCROACHMENTS

Location ____________________ Vehicle Description ____________

Run No. ____________________ Marking Type ____________

Date ____________________ Vehicle Width ____________

Day/Night ____________________ Dry/Wet ____________

Event No.	Encroachment Type (Edge of Pavement, Centerline)	DMI		Time		Maximum Amount of Encroachment (No. of Tire Widths)	Ave Spd	V
		Begin	End	Begin	End			

Figure 16. Encroachment data reduction form.

Erratic Maneuvers &
Brake Applications

Location ________________
Run No. ________________
Day/Night ________________
Total Erratic Man. _____
Total Brake Appl. _____

Vehicle Description ________________
Dry/Wet ________________
Marking Type ________________
Vehicle Width ________________

Event EM or BL	Location DMI

Event EM or BL	Location DMI

Figure 17. Erratic maneuvers/brake application data reduction form.

VIDEO IMAGES

Light(D/N)____ Weather(D/W)____
Marking(2/4/10)____ Date_______
Time_______ Run_____ Tape_____
Tape Time_______

Vehicle Measurements				
Pt.	L/R	Width Lane	Width Car	L/D

Critical Points				
Milepost	Spd	Car Width	From Ctr. Line	Veh. T/C

Light(D/N)____ Weather(D/W)____
Marking(2/4/10)____ Date_______
Time_______ Run_____ Tape_____
Tape Time_______

Vehicle Measurements				
Pt.	L/R	Width Lane	Width Car	L/D

Critical Points				
Milepost	Spd	Car Width	From Ctr. Line	Veh. T/C

Figure 18. Video image data reduction form.

APPENDIX C - STATISTICAL ANALYSIS

Prior to conducting the analysis, several statistical tests were conducted to ensure the data met the necessary assumptions for the selected statistical procedures. Presented below are the results of these tests for each of the MOE's: average running speed, distance from the lane line (lateral placement), lateral placement variance, and encroachments.

AVERAGE RUNNING SPEED

Figure 19 is a plot of the residuals against the estimated values for the ANOVA conducted on this variable. The results indicate that the variance is constant. This result was confirmed by the results of the Bartlett test for homogeneity of group variances which produced a P-value of 0.798.[19]

LATERAL PLACEMENT

An initial ANOVA was conducted with the variable CDIST. Examining the plot of residuals for the model (see figure 20), it was noted that the error terms were not constant, i.e., problems of heteroscedasticity. This was confirmed with a Bartlett's test which produced a P-value less than 0.001. There were also problems of normality as noted by the normal probability plot in figure 21.

Several transformations of the data were attempted to correct for the problem, including:

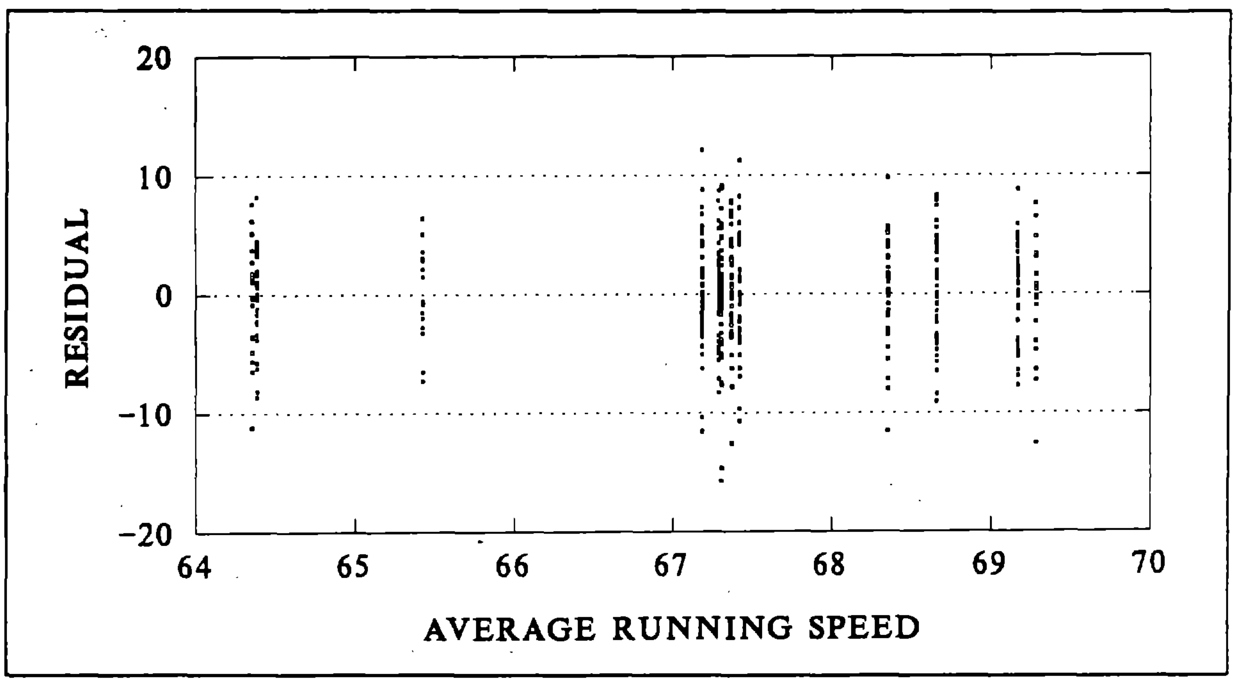

Figure 19. Residual plot for average running speeds.

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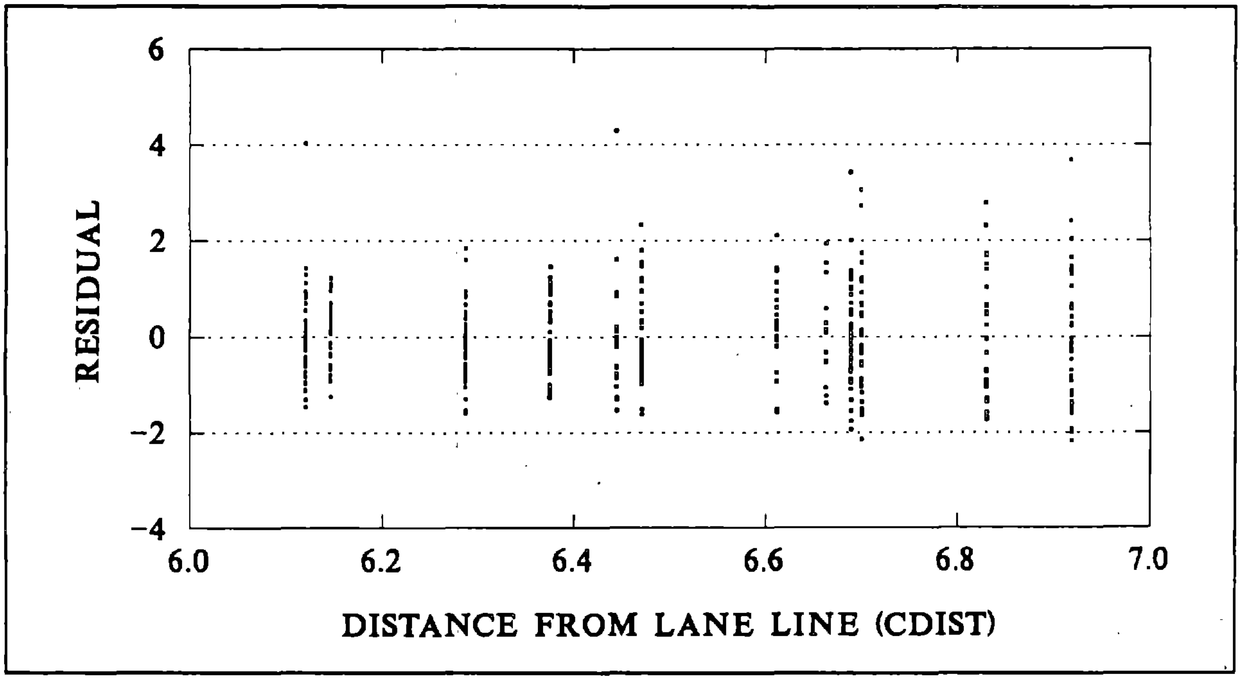

Figure 20. Residual plot for lateral placement (CDIST).

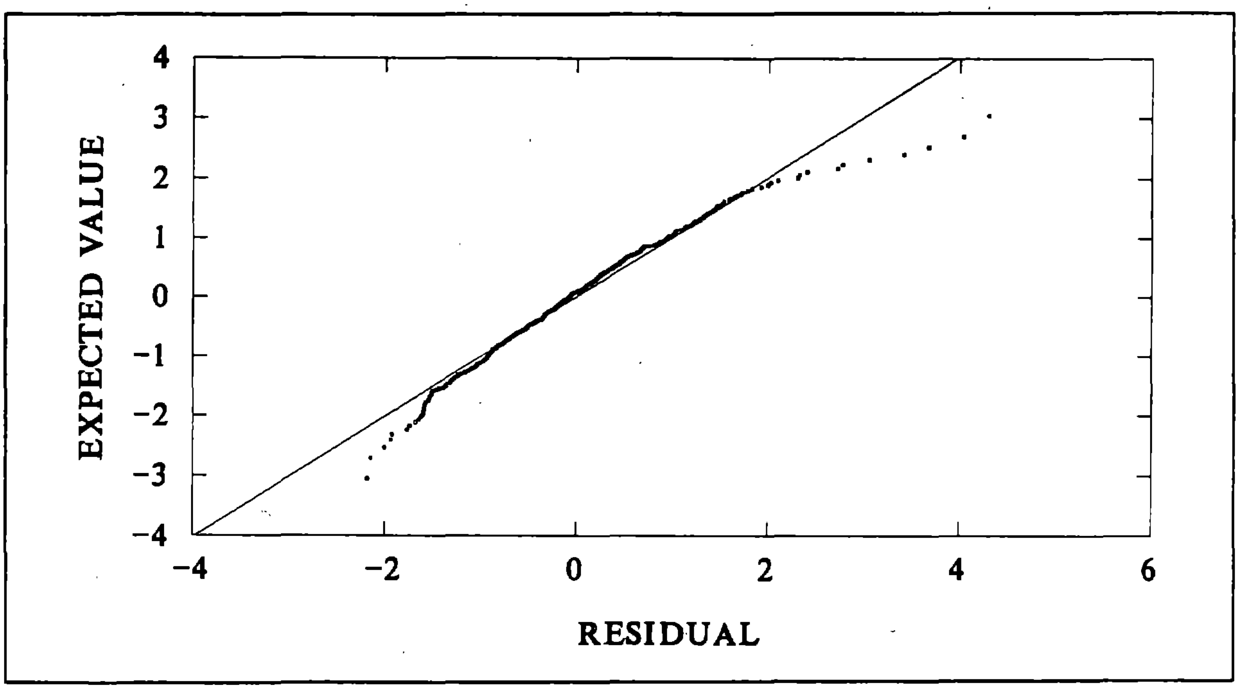

Figure 21. Normal probability plot for lateral placement (CDIST).

1) $CDIST' = \frac{1}{CDIST}$

2) $CDIST' = \frac{1}{CDIST^3}$

3) $CDIST' = \frac{1}{CDIST(\log CDIST)}$

The third transformation above was the one selected which corrected for both problems (heteroscedasticity and normality) to an admissable extent. The plot of residuals for this transformed variable is shown in figure 22 and the normal probability plot in figure 23.

If a significant difference occurred in the transformed variable, it follows that the difference in the original variable has the same level of significance.[19]

LANE PLACEMENT VARIANCE

This variable was not expected to follow a normal distribution since it was, in fact , a measure of variance. This was confirmed with a normal probability plot as shown in figure 24. As a result of this fact, the nonparametric Kruskal-Wallis test was selected for the analysis. The only assumption which must be met for this test is that the population distributions are continuous and of the same shape. As shown in figure 25, the data follows a continuous chi-square distribution and thus, meets the necessary assumptions.

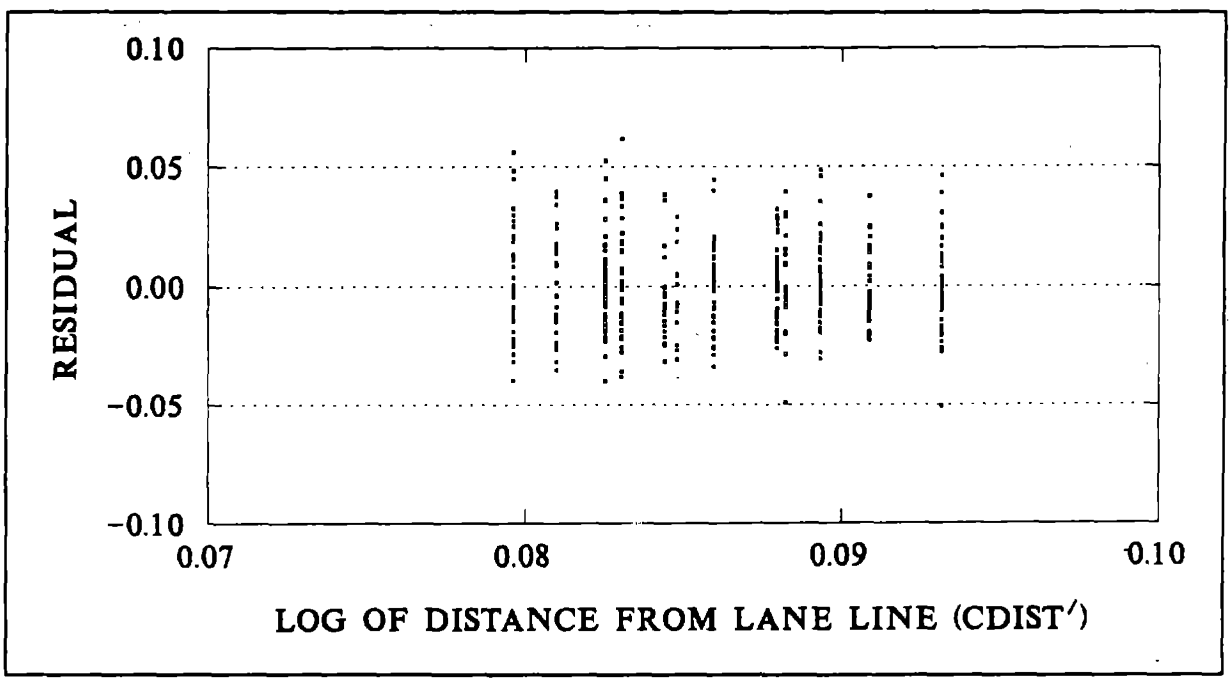

Figure 22. Residual plot for transformed variable CDIST′.

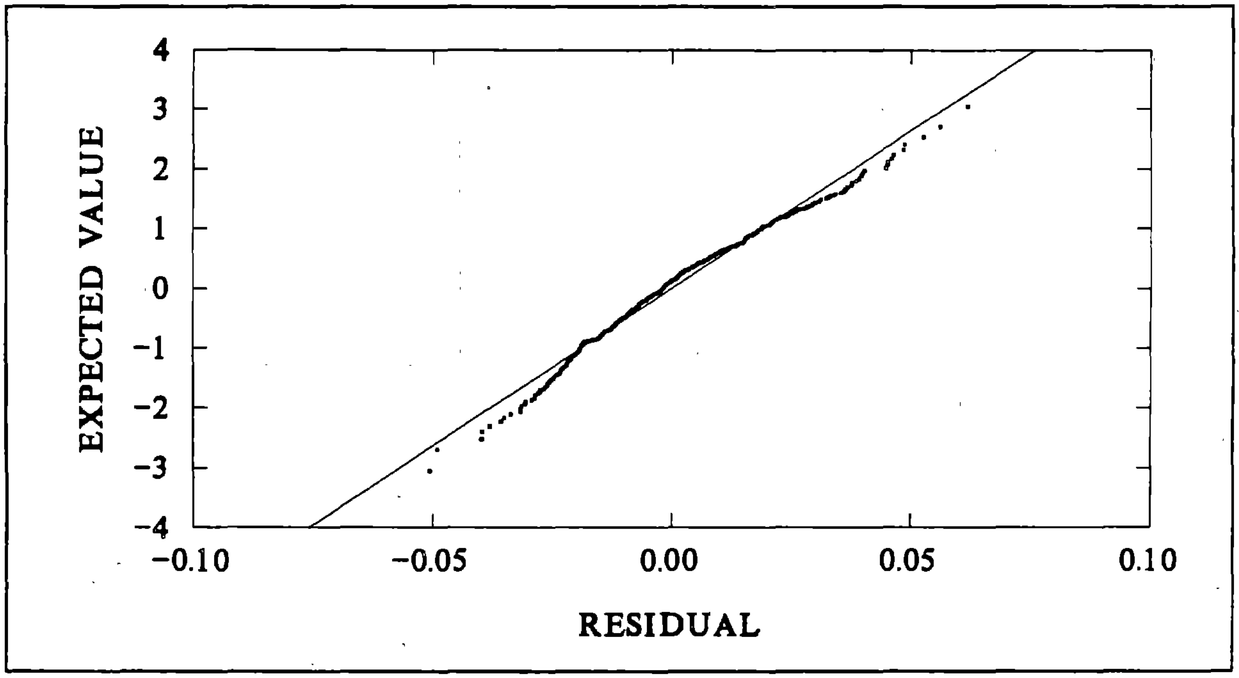

Figure 23. Normal probability plot for transformed variable CDIST′.

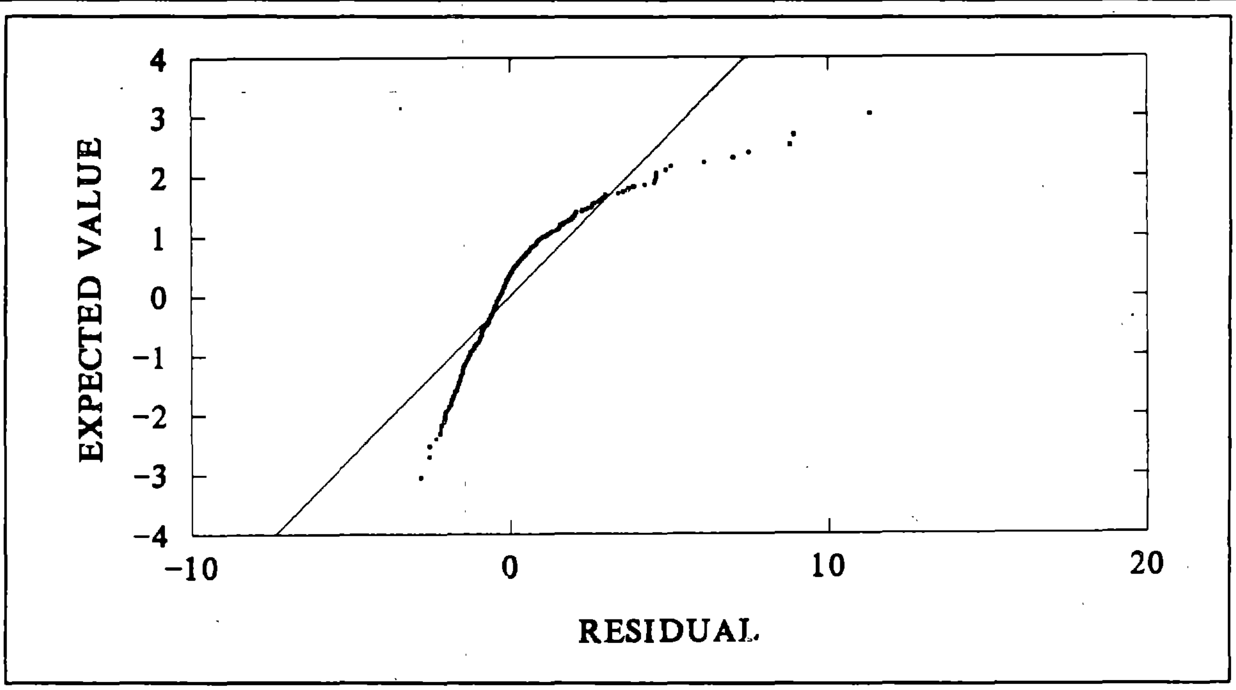

Figure 24. Normal probability plot for lateral placement variance.

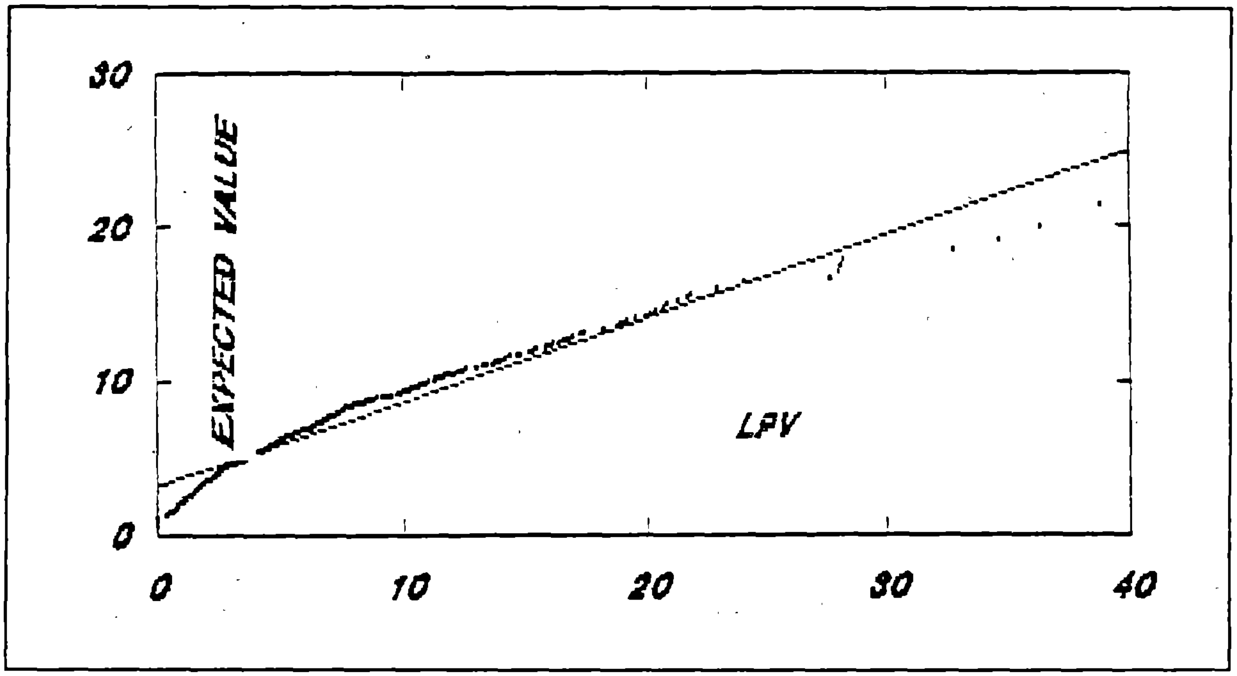

Figure 25. Chi-square probability plot for lateral placement variance.

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