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LIMITED SIGHT DISTANCE WARNING FOR VERTICAL CURVES

Final Technical Report

November 1984

Prepared for

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16. Abstract

This is a summary of the procedures and findings of a study of highway signs to warn of restricted sight distance due to crest vertical curves. Driver awareness, understanding, and response to the existing LIMITED SIGHT DISTANCE (LSD) sign and several alternative signs were measured. Following a study of performance requirements, a large number of preliminary alternative sign designs were tested in a laboratory setting. Further laboratory testing of the five most promising designs was conducted to assess driver comprehension and assimilation. The two most promising verbal and symbol alternatives were next evaluated in a controlled field study and an observational field study, conducted at several vertical curves on two-lane rural roads. The controlled study indicated that both of the alternative signs - one with the legend SLOW HILL BLOCKS VIEW and the other with a symbol in combination with that message - were superior to the LSD sign. The symbol sign with the supplementary legend SLOW HILL BLOCKS VIEW is recommended to replace the existing LSD (MUTCD W14-4) sign.

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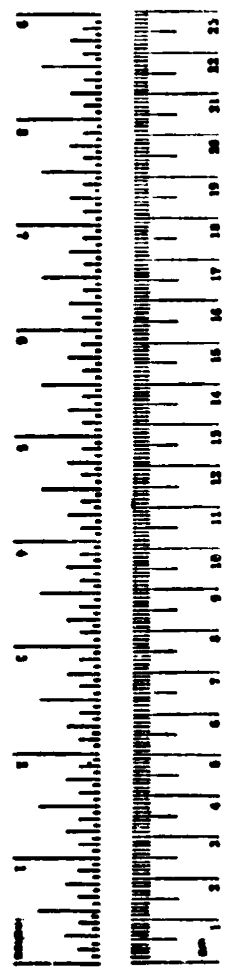
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

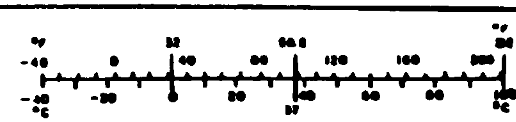
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Contemporary highway design practices reflect the understanding that the geometry of the roadway and its design features must adequately satisfy the safety and operational requirements of the vehicle and driver. Prominent among those highway characteristics and features are vertical and horizontal alignment, superelevation, delineation, signals, signs, and lighting. One of the most important aspects of the highway design is its ability to provide sufficient sight distance so that a driver has a preview of the roadway and traffic ahead, and also has enough time to properly respond to the situation ahead. Modern highways therefore are designed and built with horizontal and vertical curvatures that are appropriate for the desired speed and composition of traffic.

Many older highways, however, were not conceived and constructed using a fully satisfactory design. Instead, these roads evolved from the old pathways on which much slower vehicles were once common. The gradual improvements to the roadway, especially through upgrades in paving, enabled traffic to operate more smoothly and at higher speed. However, on a great number of two-lane rural roads, the horizontal and vertical alignment was not upgraded to match the level of service offered by the roadway surface.

On two-lane roads with crest vertical curves that have not been designed to modern standards, drivers cannot see far enough beyond the crest of the hill to determine whether a hazard exists on the road ahead. Such hazards may include debris on the roadway, pedestrians or bicyclists, animals, or other vehicles. The situation in which an intersection exists just beyond the hill crest, where neither the mainstream nor crossing traffic can see each other's approach, is especially hazardous. Traffic that is either attempting to pass or has wandered into the opposing lane on the opposite side of the hill poses an equally grave hazard. In all cases, the problem is that the motorist does not have the time that is needed to execute a successful avoidance maneuver.

Such situations most often occur on lower volume, two-lane rural highways which primarily carried local traffic at one time. Accordingly, local drivers who know of the inherent danger at these sight distance-restricted vertical curves tend to exercise greater caution by slowing down or otherwise being more attentive during their approach. Unfamiliar drivers, however, who may represent a large proportion of the traffic on highways that service popular recreational areas, generally do not exercise such cautious behavior.

A direct solution to the sight distance problem at crest vertical curves is to upgrade the vertical curvature to design standards through highway reconstruction. This is very expensive, and may not be cost-effective in most cases. Another solution is to reduce the speed limit so that sufficient response time is provided through lowered vehicular speed. It is not advisable to create frequent and abrupt speed limit changes on what are normally higher speed roadways, though. A more cost-effective and rational approach is to warn the motorist of the nature of the (potential) hazard ahead and advise of the appropriate safe speed through the hazard area.

The warning approach was adopted through the use of a verbal warning sign with the legend "LIMITED SIGHT DISTANCE," designated W 14-4 in the Manual on Uniform Traffic Control Devices (1), supplemented with a speed advisory panel.

This traffic control device was approved by the Federal Highway Administration in 1976. However, the effectiveness of the sign, either with or without the speed advisory plate, has been questioned. Because the sign legend uses terminology that is familiar to traffic engineers but not necessarily understood by the average motorist, it was not known whether the sign was comprehended quickly enough to result in an appropriate increase in alertness and/or speed reduction, or was indeed understood at all. In 1982, the Federal Highway Administration sponsored a research effort directed to answer that and other questions.

This report presents the findings of the research project entitled "Limited Sight Distance Warning for Vertical Curves." The overall objective of the project was to develop an improved warning device that will alert drivers to the sight distance restrictions associated with below-standard vertical curves on secondary rural roads. Since the approved LIMITED SIGHT DISTANCE warning sign was believed to be poorly understood and not well heeded by the driving public, the research objective was translated into a research plan to:

1. Learn what is known about the performance of existing LSD and other similar signs as well as the rationale for design and evaluation of highway signs;

2. Generate a set of alternative verbal and symbol signs to convey the appropriate message;

3. Design and conduct a laboratory-type study to evaluate the effectiveness of each of the signs;

4. Design and conduct a controlled and observational field study to evaluate the signs' performance in real-world conditions; and

5. Develop recommendations for the application of the warning device.

This report is organized in seven chapters and an appendix. Chapter 2 presents the findings of a review of previous research and other literature to identify the performance objectives and requirements for the required warning device. Chapter 3 documents the procedures used to develop a preliminary set of candidate warning signs that were evaluated in detail during the laboratory experiments described in Chapter 4. The most effective verbal message and symbol sign candidates that were identified in the laboratory study were then subjected to both controlled field tests, described in Chapter 5, and an observational field study, documented in Chapter 6. Based on the findings of the entire research effort, warrants, guidelines and criteria for the selection, placement, and location of the warning device were developed and are presented in Chapter 7. The Appendix contains the technical specifications for the appearance of the sign.

2. IDENTIFICATION OF PERFORMANCE OBJECTIVES

It is most convenient to divide the subject matter of the literature into separate sections dealing with vertical curve geometry and sight distance policy, sign visibility/conspicuity/legibility, performance of limited sight distance warning signs, effectiveness of other classes of signing, and laboratory and field measures of effectiveness.

2.1 Vertical Curve Geometry and Sight Distance

A crest vertical curve is the parabolic curve connecting the two approach grades on either side of a hill. For vehicles approaching the crest of a vertical curve, the hill obstructs the view of the road ahead. Current design practices for crest vertical curves are given in "A Policy for the Geometric Design of Rural Highways" published by the American Association of State Highway and Transportation Officials (AASHTO) in 1966 (2). Design policy for crest vertical curves is based on the need to provide drivers with adequate "stopping sight distance," that is, enough sight distance to permit drivers to see an obstacle soon enough to stop for it under some set of reasonable worst case conditions. The parameters which determine sight distance on crest vertical curves are illustrated in Figure 1. They are the change of grade (A), the length of the curve (L), and the height above the ground of the driver's eye (H_e) and the obstacle to be seen (H_o). The length of the curve required to provide a given sight distance (S) is given by the following expression:

$$(1) \qquad L = \frac{A\,S^2}{100\,(\sqrt{2H_e} + \sqrt{2H_o})^2}; \quad L \geq S$$

Solving for sight distance gives

$$(2) \qquad S = 10\,\sqrt{L/A}\,(\sqrt{2H_e} + \sqrt{2H_o})$$

For a given change of grade, the longer the curve length, the milder the curve and the greater the sight distance. Design values for these parameters are specified in the AASHTO design guide (2).

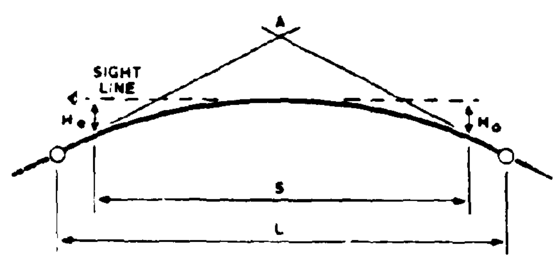


Figure 1. Hill Crest Geometry and Sight Distance

The criterion for setting sight distance on vertical curves is the distance required to stop for an obstacle in the road. The expression used in the AASHTO design guide to calculate stopping distance is

$$(3) \qquad D = 1.467\,(RT)\,V + V^2/30f$$

where D is stopping distance in feet, RT is reaction time in seconds, V is speed in mph and f is the tire-pavement coefficient of friction. The constants translate mph into feet per second. Current practice assumes relatively poor conditions for stopping: a 2.5 second reaction time and a locked wheel, wet pavement stop. The effective pavement friction values assumed in the AASHTO design guide range from .36 for stops from 30 mph (48 kph) to .29 for stops from 70 mph (112 kph). The obstacle height set by AASHTO for vertical curve design is six inches (15 cm).

Farber (3) performed sensitivity analyses of the effects of change in eye height, object height, friction, and speed on stopping distance on crest vertical curves. He found that stopping distance was relatively insensitive to a reasonable range of changes in driver eye height, but is very sensitive to speed, friction, and reaction time.

Thus, stopping distance on vertical curves that are of inadequate length or are substandard according to other design criteria, and where major redesign, repaving, or excavation is not feasible, could most efficiently be made safer by modifying a driver's approach speed and/or reaction time. For 55 mph (88 kph) traffic, stopping distance decreases 81 ft for every one second reduction in reaction time. Similarly, stopping distance decreases about 16 ft/mph (3 m/kph) reduction in speed.

2.2 Visual Performance Associated with Signs

One of the earliest concerns of traffic engineers was to know the distance over which a traffic sign could be seen, recognized, and comprehended. As early as 1939, Forbes (4) reported the legibility distance of a verbal message sign as a function of letter style and letter size. For wider letters, such as Series D (5), it was found that the legibility distance in feet was approximately equal to 50 times the letter height in inches, for observers with 20/20 vision. For narrower, Series B letters, the legibility distance in feet was found to be approximately 33 times the letter height in inches. It was also shown that when the time to view signs was limited to about one second, the legibility distance was reduced between 10 and 15 percent. Forbes demonstrated that no more than three to four familiar words should be used where a minimum reading time and adequate comprehension is desired.

When the ability to see a sign is reduced, either by poor visual acuity of the driver or by environmental conditions, the legibility distance is reduced. For visual acuity problems, the legibility distance is reduced in direct proportion to the acuity measure (4, 5). That is, a driver with 20/40 vision will recognize a sign only at half the distance needed by a driver with 20/20 vision. Interestingly, when visibility is degraded, a greater decrement in performance for verbal signs than for symbol signs has been reported (6).

2.3 Performance of Vertical Curve Warning Signs

Although numerous research efforts have attempted to evaluate the performance of traffic control signs used to warn motorists of various hazardous conditions, only one study has specifically addressed the limited sight (LSD) warning sign.

Christian et al. examined the effect on motorists' behavior and accidents associated with the LSD signs used on vertical curves in New York State (7). It was noted that the availability of the LSD sign had allowed many substandard (according to NY and AASHTO) vertical curves to be treated with resurfacing and sign installation, rather than improving the vertical curvature. In fact, the sign was intended for use where the resurfacing and/or other minor road improvements would result in increased speeds significantly (5 mph) above the design value associated with the vertical highway alignment.

It was found that at 14 of the sites examined, mean and 85th percentile speed showed no significant change, while 5 sites exhibited a significantly lower speed when the LSD sign was removed, compared to speeds when the sign was in place. It appeared that the mean and 85th percentile speeds were more closely related to the posted speed limit than to the advisory speed shown on the plate. The results of a survey received from 631 of more than 1400 motorists whose license numbers were recorded at the test sites indicated that only 17 percent understood the specific meaning of the LSD sign, 47 percent knew that it was a warning with an advisory speed but did not realize that it referred to the hill, 29 percent knew it was a warning but thought the advisory speed was a speed limit, and 7 percent did not know the meaning at all. It was also reported that the LSD sign was the most frequently used (2.13 per mile-1.28 per km) of all signs at sites where it was used, and was second to the horizontal curve warning as the most frequently used sign (1.59 per mile-.95 per km) at all recent highway rehabilitation projects where signing had been installed. An examination of accidents provided no conclusive results.

The most obvious explanation for the apparent ineffectiveness of the LSD sign is that its message is simply not understood by very many people. However, part of the problem may be that the nature of the hazard is not apparent. Unlike the hazards cited by other warning signs, limited sight distance has no tangible manifestation. Generally speaking, traffic signs must be credible if they are to be obeyed (8, 9, 10). A curve warning sign is always followed by a curve. But even after a driver has topped the crest of a vertical curve he may not be aware of the extent to which his sight-distance was curtailed. If this is so, then drivers would quickly learn to ignore the signs. This poses the question of whether such devices should be limited to sites where the crest hides some specific hazard such as an intersection or business driveway. It is worth noting, in this regard, that of the 11 accidents where limited sight distance was deemed a possible or likely cause by the New York State researchers, seven involved intersections or driveways.

2.4 Other Hazard Warning Signs and Devices

Studies of driver response to warning signs in other applications have shown varied effects. Hanscomb (11) observed the effect of slippery-when-wet (SWW) signs on vehicle speeds in wet weather. The standard SWW symbol depicting a skidding car had no effect. Adding the message "SLOW WHEN WET" decreased speeds at one of three sites. The use of flashing beacons was effective, especially when messages of higher specificity -- "SLOW WHEN FLASHING" and "MAX SPEED X MPH" -- were used to supplement the SWW symbol. Interviews with drivers who passed through the sites revealed that the high conspicuity devices, i.e., the SWW signs with flashing beacons, were more likely to be noticed and correctly identified. Also, drivers generally gave lower estimates of what might be a safe speed when flashing beacons were present.

In an evaluation of the effectiveness of techniques for warning motorists of slow moving vehicles ahead on uphill sections of two-lane, rural roads, Lanman et al. (12) studied three "SLOW MOVING VEHICLES AHEAD" (SMVA) signs: first with the message alone, second with the SMVA message plus flashing beacons, and the third with the SMVA message, beacons, and a plate with a "WHEN FLASHING" indication. The speed was reduced 1-3 mph (2-5 kph) compared to the no-sign condition, with the active devices having a somewhat greater effect.

Lyles (13) studied the effect of warning signs at two intersection approaches with limited sight distance (less than 500 feet). At one site the intersection was preceded by a horizontal curve and in the other, by a crest vertical curve. Five different warning devices were evaluated: (1) the standard intersection cross road warning symbol sign, (2) a warning sign with the message "VEHICLES ENTERING," (3) a sequence of three regulatory and warning signs: a "REDUCED SPEED AHEAD" sign, a cross road sign and a 35 mph speed limit sign, (4) a "VEHICLES ENTERING" sign with constantly flashing beacons, and (5) the same sign with a "WHEN FLASHING" plate, with beacons activated only in the presence of cross road traffic.

A vehicle (van) was deliberately positioned on the cross road at the intersection on 50% of the trials. Effectiveness was expressed in terms of speed changes between the "entry point" upstream of the sign area and various points in the approach and in the intersection itself. Overall the standard cross roads and "VEHICLES ENTERING" signs had less speed reducing effect (0.5-2 mph; 1-3 kph) than the regulatory-warning sequence and the beacon signs (4-5 mph; 7-8 kph). This trend was the same at both sites, and within the two groupings there was little difference between signs, i.e., the regulatory warning sequence was about as effective as the beacon-enhanced signs. Familiarity with the site had no apparent effect on the outcome.

A survey of motorists passing through the site revealed that the regulatory-warning sequence and beacon-enhanced signs were twice as likely to be recalled as the simple signs. Also, the van on the cross road was reported as having been seen more often when the regulatory/warning signs or beacon signs were used.

In a study of the effect of warning and regulatory signs on horizontal curves on rural roads, Lyles (14) dealt with a problem similar to that discussed by Christian (8), where a highly used curve warning sign with an advisory speed plate is ignored, perhaps because it is overused. Sign types included the standard, curve warning symbol sign (W1-2), placed at 300 ft (92 m) in one condition and at 700 ft (215 m) in another, W1-2 with a non-standard speed advisory message, W1-2 with a standard regulatory sequence, and a W1-2 with standard speed advisory plate. No sign condition was found to be consistently and significantly better than any other across all sites and conditions. For all sign conditions, the location of the point of lowest velocity was downstream from the beginning of curvature, rather than at a more desirable point prior to entering the curve. This suggests that drivers received the information needed to adjust their speed more from their sense of lateral motion than from information posted on a sign.

Ritchie (15) had test subjects drive through curves of varying radii, some with and some without curve warning and advisory speed signs. His results indicated that lateral acceleration was somewhat higher on curves with signs than on curves without signs. However, as speed increased these results were interpreted to mean that the signing serves to reduce uncertainty and increases the confidence with which drivers proceed. Lateral acceleration appeared to be a key variable in speed choice. Drivers apparently provide themselves with a great margin for safety as roadway speed increases; the speed choice represents a smaller fraction of the speed at which lateral skidding would commence than on lower speed roads.

Stockton et al. (16) cited Ritchie's findings as the basis for concluding that curve warning signs are not safety related and that they are unnecessary on low volume rural roads except where sight distance restrictions would not allow drivers sufficient time to slow for the curve. In such cases, advance warning consisting of the curve warning sign alone is appropriate where the curve speed should be between 10 and 15 mph (17-25 kph) slower than the approach speed. A speed advisory plate is recommended where the speed difference is greater than 15 mph (25 kph).

2.5 Flasher-Augmented Warning Signs

The use of flashers to increase the conspicuity of warning signs has been examined in numerous research efforts, and positive results were always indicated. When used to warn of the presence of a sight-restricted rural intersection, the class of warning signs that included a flasher-augmented system resulted in a 1.6-3.2 mph (2.7-5.3 kph) speed reduction of the sign location, compared to 0.8 mph (1.3 kph) without flashers (13). Motorists were twice as likely to have been aware of the presence of a hazard (a parked van) at the site, as well. Flashers used to draw attention to signs warning of work zones on rural highways resulted in a 3-4 mph (5-7 kph) greater speed reduction than that obtained from signs without flashers in a short work zone, and a 7.5 mph (12.5 kph) slower speed than that achieved by the standard sign (17). In a study of the effectiveness of flashing lights used in conjunction with regulatory school zone speed restriction signs, flashers resulted in an average speed reduction of 3.6 mph (5.0 kph) across all sites (18). On roads that normally were limited to 55 mph (92 kph), a 10 mph (17 kph) reduction was obtained, although a 30 mph (50 kph) reduction was desired. Hanscomb (11) reported a 9 percent reduction in speed on high speed roads where flashers and signs were used to warn of a wet weather skidding hazard. Significantly, where flashers were used, all motorists reduced their speed to a level at or below the critical speed, while without flashers, the fastest quartile did not. The active signs were more prone to be observed, properly identified, and obeyed.

It may be concluded that where flashers are used, and the hazard is not obvious, regardless of the accompanying sign, a speed reduction of at least 2-3 mph (3-5 kph) may be realized. Where the nature of the hazard is more clearly identified by the sign, the speed reduction is likely to be greater, and the motorist's attentiveness is likely to be heightened. Where the nature of the hazard is obvious, as in the case of slippery conditions due to rain on a curve, flashers are likely to be most effective in warning drivers to reduce their speed and be more attentive.

2.6 Experimental Techniques and Measures of Effectiveness

Previous investigations of the effectiveness of hazard warning signs for highways have primarily utilized observational field study and survey techniques. However, development and evaluation of both verbal and symbol signs have also been accomplished through laboratory studies. Field studies are, in general, more operationally valid in determining the actual effect of a sign on traffic behavior. Laboratory studies can measure the effects of a sign on individual driver behavior, but have less face validity. Further, the validity in a statistical sense of laboratory studies of sign effectiveness has not been well established. Controlled field studies, which are a kind of hybrid combining aspects of both laboratory and field techniques, somewhat bridge the gap in face validity, but their level of validity has not been clearly established for sign evaluation.

Observational field studies have resulted in the analysis of a variety of measures of vehicle trajectory since techniques for sensing and recording such information have become available. In several studies using similar techniques (11, 12, 13, 14, 17) spot speeds at various locations along a 2,000 ft (610 m) length of instrumented roadway were measured to provide:

- o entry speed
- o speed at intermediate points
- o speed at hazard warning sign
- o speed at hazard
- o speed after hazard (exit speed)
- o initial speed reduction
- o maximum speed reduction

Each dependent measure provided a different point of view of the effects of a hazard warning sign, and the most strongly affected were generally the speed change variables.

Observational studies have also utilized survey techniques that seek to establish the level of attentiveness of the driver associated with the traffic control device under study (7, 11, 13). Attentiveness has been measured through querying the driver on his recall of the sign message, the presence of parked vehicles or other aspects of the hazard, and self-assessment of attentiveness. Recall of the sign message provides a measure of the strength of the message, as well.

Less complex field studies have utilized simple counts of violations of turning prohibitions and other prohibitory-type messages (19).

Controlled field studies to evaluate signs were conducted as early as 1939 (4), when the legibility distance was of principal concern. More recently a number of investigations have also used that technique to evaluate signs. Ritchie (15) measured the speed of vehicles operated by paid test subjects to examine the effectiveness of curve warning signs. Dewar and Ells (20) had subjects classify signs as either warning, regulatory, or informational, and identify their message while driving under normal and specially modified conditions. The distance from the sign when it was classified and then identified was the dependent measure. This technique suffered from the rather weak discriminatory power of timing verbal responses. In a later set of experiments, Ells and Dewar (6) somewhat compensated for the verbal response time problem by having the subjects classify signs using a single syllable response -- "yes" or "no" -- to identify the warning-regulatory dichotomy while driving an automobile. The legibility distance, defined as the maximum distance from the subject at which the sign could be classified and identified, was recorded. In a study performed by Summala and Naatamen and reported by Dewar (21), subjects were required to name all the traffic signs they saw as they drove along a 160 mile route in Finland. The subjects were able to report approximately 97 percent of all signs on the route, a much higher number than reported in earlier studies of a similar nature.

Many laboratory-based studies have been conducted to evaluate highway signs. The most noteworthy of those have been conducted by Dewar in Canada and Easterby in England.

A simple ranking test has been used to determine the public's preference for alternative signs portraying the same message (24). In this technique, each respondent ranks a set of alternative signs, from best to worst, using the general criterion of how well the sign conveys the intended message.

The most widely used measure of effectiveness in laboratory studies is the frequency of correct responses in identifying the category or meaning of a sign displayed to a subject. Experimental techniques have included timing and recording verbal responses (6, 20, 22), timing required subject responses such as pressing the proper key on a keyboard (22), and simply recording subject responses with no time limit involved (23). In an effort to examine effects unrelated to response latency, and also to increase the difficulty of the requirement to name and describe the meaning of a sign, tachistoscopic techniques have been used to provide a brief, fixed-duration exposure to each sign tested (6, 19). Using that technique, the frequency of correct responses provides both an absolute measure of sign effectiveness as well as a relative measure for comparing alternative signs with the same message.

Techniques in which a respondent selects a scale value for a particular attribute (such as clarity of message) of the sign in question have been used on several occasions. Freedman (26) used a ten-point rating scale in conjunction with a written matching test to evaluate a set of passenger/ pedestrian oriented symbol signs for U.S. DOT. Dewar (25) used the semantic differential technique (27) for the evaluation of traffic sign messages. It was found that these scores were highly correlated with comprehension and partially correlated with glance legibility of symbolic messages.

3. DEVELOPMENT OF PRELIMINARY ALTERNATIVES

The initial developmental effort to evaluate limited sight distance warning devices was directed toward, first, creating a wide variety of candidate verbal messages and symbols, then selecting the five most promising candidates for further, more detailed testing.

3.1 Message Development

The development of verbal referents was based on the provision of three elements of the message. The first, the preparatory element, serves to indicate the appropriate degree of attentiveness that the driver must exhibit. As disclosed in the review of previous research, that is often accomplished by flashing beacons or sequences of signs which provide sufficient redundancy to heighten the driver's attention. The second element indicates the action that must be taken by the motorist. Speed advisory messages are the most frequently seen action indicators on warning signs. The final element concerns the identification of the hazard to the motorist. In many verbal signs, and in all symbol signs, only the hazard is explicitly identified, while the other two elements are assumed to be understood by the driver.

The verbal messages created as alternatives to the LSD referent utilized combinations of the following message elements:

1. Preparatory Element

   - CAUTION
   - DANGER
   - BE ALERT (an action element that serves a dual role)
   - SLOW/SLOW DOWN (an action element that serves a dual role)
   - (none specified)

2. Action Elements

   - BE ALERT
   - SLOW/SLOW DOWN
   - (none specified)

3. Identification Elements

   - OBSTRUCTION/BLOCKAGE of line of sight
   - LIMITATION/RESTRICTION of line of sight
   - HILL identified as object causing hazard
   - VIEW/VISION/SIGHT DISTANCE identified as sense of limitation

The most succinct of these elements were combined to form the following referents:

CAUTION OBSTRUCTED VIEW
CAUTION HILL BLOCKS VIEW
BE ALERT HILL BLOCKS VIEW
DANGER HILL BLOCKS VIEW
SLOW HILL BLOCKS VIEW
SLOW DOWN HILL BLOCKS VIEW
HILL BLOCKS VIEW
HILL OBSTRUCTS VIEW
HILL RESTRICTS VIEW
OBSTRUCTED VIEW
OBSTRUCTED VISION
LIMITED VISIBILITY
LIMITED SIGHT DISTANCE

The verbal message signs using these referents are shown in Figure 2.

For symbol sign development, an attempt was made to identify the strongest images that could convey the need for attentiveness, as well as the general nature of the problem of restricted sight distance, in a way that would be clear to the motorist. A graphic artist produced the symbol images shown in Figure 3. The symbols ranged from an abstract image of generally obstructed vision (S8), through attempts to convey the vertical and longitudinal motion imparted by steep hills (S3 and S4), to profile views of the road ahead (S1, S4, S7), to elevation views showing potential hazards (S2, S5, S6, S9, S10). The difficulty of symbol development for the limited sight distance problem is that the symbol must convey the notion of a hazard due to the absence of information, not necessarily the continued presence of an explicit hazard.

3.2 Preliminary Ranking Test

The initial set of thirteen verbal messages and ten symbols, shown in Figures 2 and 3, were evaluated by employees of Ketron, Inc., who rank-ordered the stimuli according to their judgment of the appropriateness of each stimulus to the referent traffic condition. The outcome of this procedure was the designation of two verbal messages, and two symbols, which reflected the greatest consensus as potentially effective warning devices in situations where a driver's forward visual field is obstructed by a crest vertical curve.

3.2.1 Respondents

A sample of forty-one respondents performed rankings of the various stimuli. Eighteen males and twenty-three females participated in the study, ranging between 20 and 55 years of age, and having between 4 and 37 years of driving experience. The mean age and years of driving experience of all respondents was 32.5 and 12.5, respectively.

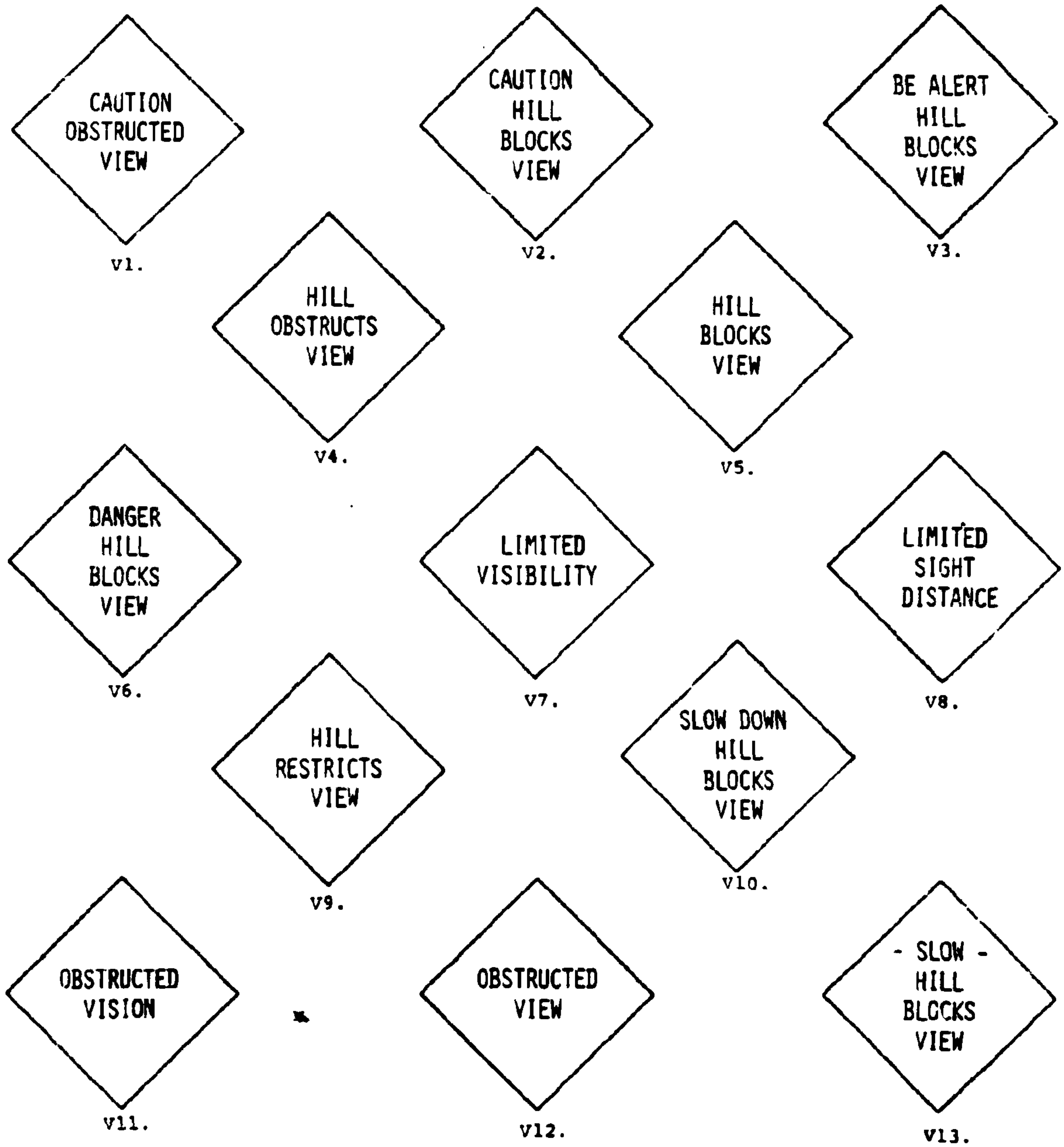


Figure 2 . Preliminary Verbal Messages.

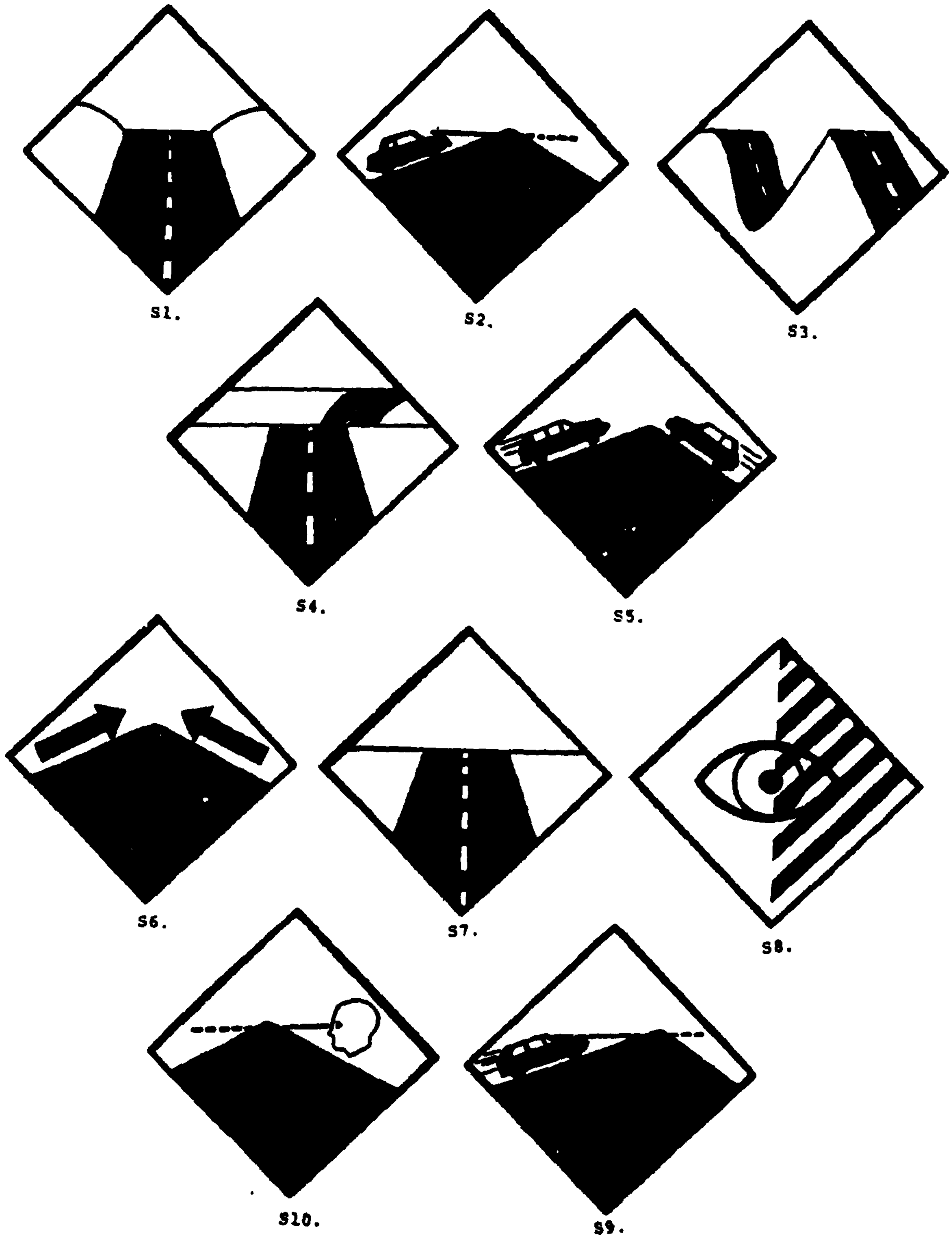


Figure 3 . Preliminary Svmbol Messages.

3.2.2 Stimulus Materials

Ten symbols, each framed in the standard MUTCD diamond-shaped format, were printed in a black-on-white graphic affixed to 4.25 in (10.8 cm) square pieces of posterboard. Similarly, thirteen verbal messages were lettered in black-on-white, and were configured in 1.5 in (3.8 cm) square diamonds in the same sort of "flashcard" arrangement described above.

3.2.3 Procedure

One respondent at a time performed preference rankings of verbal messages first, and then the symbols, with no time limit. Subjects were given the following instructions:

> "We are conducting a study to identify a highway warning sign that will effectively communicate to drivers approaching a hill crest that their vision is restricted, and that particular caution is required under such conditions due to possible hazards hidden on the other side of the hill. Your task is simply to arrange these cards bearing messages (symbols) in the order which you feel best reflects their relative effectiveness at conveying this warning. Please look at each card, one at a time, then place all thirteen (ten) in the order--best to worst--that your own judgment and experience as a driver dictates. Feel free to make as many changes in your response as you'd like, and just let me know when you've reached a final decision."

3.2.4 Analysis

A two-part analysis was performed on the data obtained in this study. First, tables relating the number of times each stimulus was ranked in each of the possible positions were prepared as shown in Tables 1 and 2. Chi-square tests were used to determine whether significant differences existed among the frequencies with which the various stimuli were placed in the highest (most preferred) positions. Since it was initially the goal to define the two best verbal messages and the two best symbols, data were collapsed across the top two positions for each set of stimuli. The findings indicated a clear and overwhelming preference for some messages (V2 and V6) over other verbal messages and symbols (S5 and S9) over other symbol messages (X^2 symbols = 30.44, sig. at .995 confidence level for 9 d.f.; X^2 verb. msgs. = 87.74, sig. at .995 confidence level for 12 d.f.). The least preferred verbal message was V8, "LIMITED SIGHT DISTANCE."

An overall index of preference was constructed, by assigning weights to each rank position to more clearly convey the rankings for each stimulus included in the study. For the symbols, a value of ten was assigned a first-place ranking, nine to a second, and so on down to a value of one for a tenth-place ranking. These weights were then multiplied by the frequency with which each stimulus appeared in each position, and the products then were summed across rankings for each stimulus. For the verbal messages, the weights ranged from thirteen, for a top ranking, down to one. With relatively higher weights assigned to relatively higher rankings, this procedure resulted in a useful measure of the collective judgment of all 41 subjects regarding the effectiveness of each symbol and verbal message. Tables 3 and 4 present the outcome of this analysis.

A normalized score, derived by dividing the index value by the number of referents in the set (10 for symbols, 13 for verbal messages), was also calculated. Thus the normalized score is a comparable measure of the strength of preference across sign type. It indicates, for example, that respondents more strongly preferred V2 than S9, which were the leading signs in each category. The percent of the maximum possible score for a referent was also calculated as another preference strength indicator. It is the actual index value divided by the maximum possible index value, which would be the maximum weight (10 for symbols, 13 for verbal messages) multiplied by the number of respondents.

3.2.5 Subject's Comments

During the debriefing session following the rank-ordering, respondent comments were solicited. A number of respondents, while ranking symbols S5 and S9 both very highly, said they believed a hybrid of these signs -- a symbol that incorporated the hill-intersecting-line-of-sight feature of S9 and the "other vehicle/ hidden hazard" feature of S5 -- would be the single most effective design. Also, several individuals expressed a preference for a symbol communicating the "hill blocks view" concept from a "driver's eye/head-on" viewpoint, rather than a side/profile view; for the most part, however, these same people rated the "head-on" perspective signs included in this study as considerably less effective than the designs (S5 and S9) which received the highest overall ratings.

Table 1. Frequency of Rank Selection for Verbal Stimuli

Number of Times in Position	Stimulus ID												
	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10	v11	v12	v13
1	4	10	2	0	0	14	2	0	1	4	0	1	3
2	3	10	5	0	0	6	1	1	1	4	2	2	6
3	3	11	5	0	1	5	1	1	0	4	2	0	8
4	5	1	6	4	4	3	3	0	3	5	0	0	7
5	2	6	6	2	3	2	0	0	4	8	0	1	7
6	7	1	5	3	11	3	1	0	5	2	1	1	1
7	2	0	0	10	3	3	4	1	4	4	4	4	2
8	1	1	3	9	5	1	0	2	10	1	1	4	3
9	7	1	1	3	6	1	3	4	9	2	1	3	0
10	1	0	1	3	4	2	5	6	1	1	9	6	2
11	5	0	3	3	2	0	3	1	2	2	8	11	1
12	0	0	1	4	1	1	13	5	1	3	5	7	0
13	1	0	3	0	1	0	5	20	0	1	8	1	1

Table 2. Frequency of Rank Selection for Symbol Stimuli

Number of Times in Position	Stimulus ID									
	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10
1	4	0	2	4	13	2	2	1	9	4
2	3	9	1	1	4	4	4	2	9	4
3	3	14	5	4	1	1	1	0	9	3
4	4	9	0	3	6	3	4	3	3	6
5	3	2	3	7	7	4	5	3	4	3
6	7	4	3	5	2	3	4	1	5	7
7	3	3	3	5	3	7	9	0	0	8
8	11	0	9	7	0	8	3	0	1	2
9	3	0	8	4	3	6	7	6	1	3
10	0	0	7	1	2	3	2	25	0	1

Table 3. Preference Index: Symbols

Stimulus	Index Value	Normalized Score	% of Maximum Score
s9	318	31.8	78
s5	309	30.9	75
s2	300	30.0	73
s10	240	24.0	59
s1	223	22.3	54
s4	219	21.9	53
s7	203	20.3	50
s6	191	19.1	47
s3	164	16.4	40
s8	109	10.9	27

Table 4. Preference Index: Verbal Messages

Stimulus	Index Value	Normalized Score	% of Maximum Score
v2	454	34.9	85
v6	423	32.5	79
v13	384	29.5	72
v10	343	26.4	64
v3	336	25.9	63
v1	317	24.4	59
v7	274	21.1	51
v5	272	20.9	51
v9	266	20.5	50
v4	250	19.2	47
v12	193	14.9	36
v11	171	13.2	32
v8	119	9.2	22

The comments provided by respondents were applied to generate an additional, new symbol deemed worthy of inclusion in later laboratory and field experiments. It is a hybrid of the two top-ranked symbols (S5 and S9) from this experiment, and is illustrated in Figure 4.

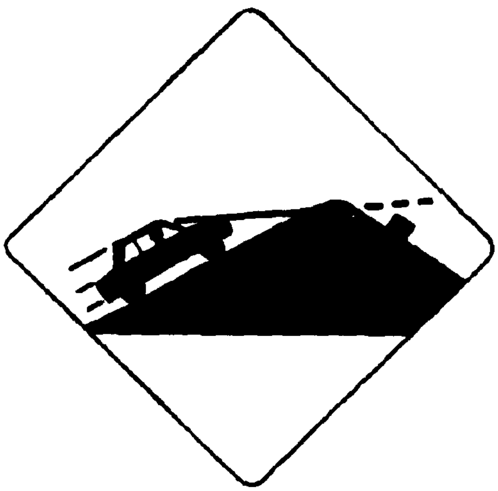


Figure 4. Hybrid Symbol Message

3.3 Conclusions Regarding Preliminary Laboratory Testing

The initial development of alternative messages utilized expert opinion, the skills of a graphic artist, and the review of the preliminary messages by 41 licensed drivers in a ranking test. The findings of this preliminary development indicate that three symbol signs (S9, S5, S2) and three verbal message signs (V2, V6, V13) were clearly superior to the other signs in each category.

The best symbol sign, S9, combined the elements of the elevation or side view, with a sharp vertical curve clearly depicted, also indicating that the driver's line of sight is blocked by the crest of the hill. The degree of hazard and the need to slow down is suggested by the graphic symbol of forward motion, depicted by dashed lines emanating from the rear of the vehicle.

The next best symbol, S5, is similar in providing an elevation of the hill but does not explicitly show a restricted line of sight. This is suggested, however, and the degree of hazard as well as the urgency of action is strongly indicated by two automobiles rushing toward each other.

The third best symbol, S2, is nearly identical to the first except that no sense of motion is depicted explicitly.

Both the first and third symbol suffer somewhat because the implied hazard, which would be something on the road beyond the crest of the hill, is not depicted. This was intentional, as explicit depiction of a specific hazard was felt to be potentially dangerous in that it might suggest one kind of hazard (debris, for example) when the hazard could be altogether different (a stalled car). The second symbol was an attempt to depict the most severe unseen hazard, an opposing vehicle rapidly approaching in the path ahead.

It was concluded that S5 should be further tested in laboratory conditions. It was further concluded that the hybrid symbol shown in Figure 4, should also be tested.

For verbal messages, the three most highly ranked were, first, CAUTION HILL BLOCKS VIEW; second, DANGER HILL BLOCKS VIEW; and third, SLOW HILL BLOCKS VIEW.

4. LABORATORY EVALUATION

4.1 Objectives and Overview

The purpose of the laboratory tests was to determine the relative degree to which the LSD sign and each of the most highly ranked preliminary verbal and symbol messages shown in Figure 5 for the limited sight distance warning were understood and quickly assimilated by motorists. A broad cross section of motorists in two states served as paid test subjects to perform the evaluations. Testing for comprehension of message content was based on a design in which each respondent saw only one of the limited sight distance warning messages along with several other warning sign messages not related to vertical curves. Assimilation trials were also based on a design in which the respondent saw only one version of the set of alternative limited sight distance messages. Rank-ordering was accomplished through analysis of the comprehension and assimilation test results. The subjects also rank-ordered the messages in a procedure identical to the preliminary evaluation described in Chapter 2 of this report.

Testing was performed at two state operated motor vehicle inspection centers in New Jersey, and also at two drivers' license photo centers in Pennsylvania. One location in each state was in a more rural area while the other in each state was in an urban area (Philadelphia). Test subjects were paid for their participation. The sample size was 256 subjects, divided evenly across all four sites.

The principal findings of the testing may be summarized as follows:

1. Of the verbal messages, "SLOW HILL BLOCKS VIEW" scored highest in comprehensibility and recognizability. It placed second best among verbal messages in the ranking test.

2. Of the symbol messages, the sign depicting two vehicles approaching each other from opposite sides of a hill scored highest in comprehensibility and second highest in recognizability. It was overwhelmingly preferred among symbol messages in the ranking test.

3. The currently recommended "Limited Sight Distance" verbal message was least comprehensible of the verbal signs, was least recognizable of all verbal and symbol signs combined, and was deemed worst of all signs by more respondents than any other symbol or verbal sign.

4. The addition of a supplementary panel ("INTERSECTION") indicating the nature of the unseen hazard neither significantly improved nor degraded the performance of the verbal sign ("CAUTION HILL BLOCKS VIEW") with which it was tested when compared to the performance of the verbal sign alone.

4.2 Experimental Design and Methodology

The laboratory study consisted of three complementary efforts -- an assimilation (speed of recognition) test, a comprehension test, and a ranking test -- for each of eight candidate signs designed to warn drivers approaching a hill crest that their vision is restricted, and that particular caution is required under such conditions due to possible hazards hidden on the other side of the hill.

4.2.1 Test Subjects

A total of 256 individuals participated as paid test subjects in this research. The age of subjects ranged from 16 to 75, with a median age of 36.5. Specifically, ages were broken down into the following categories: 1) 35 or under - 116 (45% of sample), 2) from 36 to 60 - 114 (45% of sample), and 3) 61 and over - 26 (10% of sample). Years of driving experience of subjects roughly paralleled age, ranging from less than one to 55, with a median of 18.5. The sex of test subjects was almost equally divided, with 130 (51%) males and 126 (49%) females participating in the study. All subjects received $5 for their participation.

4.2.2 Apparatus

The equipment used in the laboratory tests of comprehension and assimilation included a Kodak 760H Carousel projector and a silver, Da-Lite Vidio-Hilo screen, which were used to present stimulus slides to subjects. In addition, a Lafayette Model 43016 Tachistoscopic Shutter was attached to the projector to control the exposure duration of each slide.

The stimulus slides themselves were processed from photographs of the eight candidate warning signs, plus a group of other warning signs already incorporated in the MUTCD. Each of the signs was erected temporarily, then photographed at the same vertical curve site. Photographs were taken from a driver's perspective (i.e., at driver's eye height and in the middle of the right lane) on a two-lane road, with the hill crest located in the background at a distance of approximately 985 ft (300 m) from the

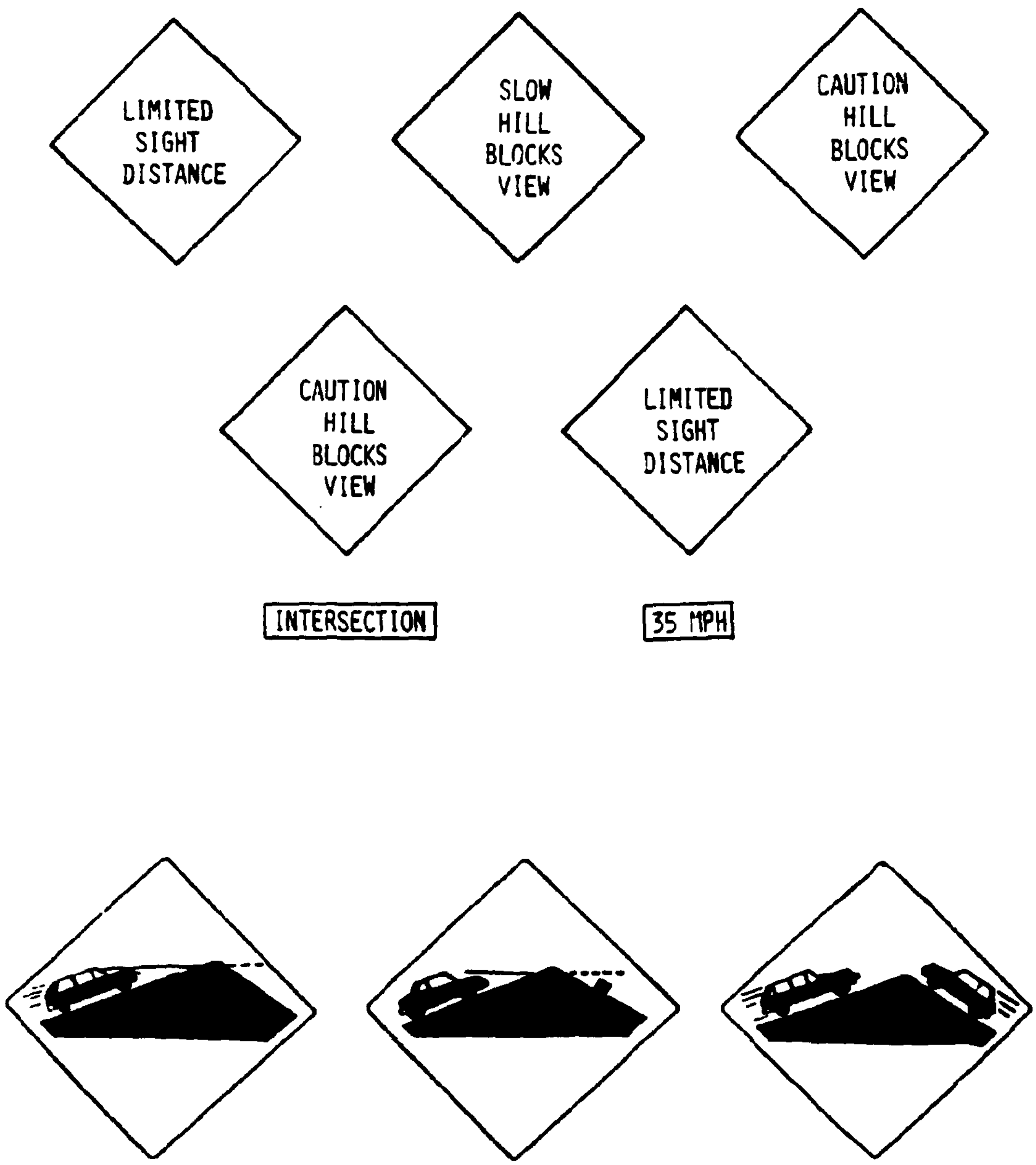


Figure 5. Candidate Limited Sight Distance Warning Signs

camera. The warning sign(s) were located adjacent to the shoulder of the roadway at a distance of approximately 85 ft (26 m) from the camera.

All warning signs utilized standard 30 in by 30 in (76 cm x 76 cm), reflectorized yellow diamond shapes, imprinted with either black symbols or 4 in (10 cm) lettering. The candidate warning devices included three signs bearing verbal messages, and three signs bearing symbols. In addition, rectangular reflectorized-yellow advisory panels were used in conjunction with two of the candidate warning signs bearing verbal messages, bringing the total number of candidate devices tested to eight -- three with a verbal message only, three bearing a symbol only, and two with both a verbal message and an accompanying advisory panel. Other warning devices, used as distractor stimuli in the study, also included three signs bearing verbal messages and three signs bearing symbols. These distractor signs are shown in Figure 6.

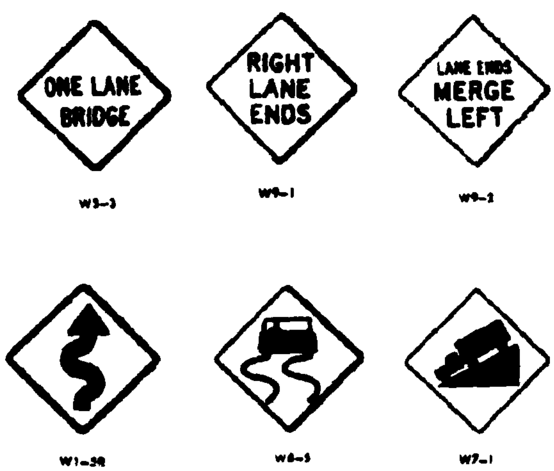


Figure 6. Distractor Signs for Laboratory Study

For the preference ranking test, six candidate warning devices, each framed in a standard MUTCD diamond-shaped format, were prepared on square pieces of white paper and attached to a cardboard backing. Three of the stimuli were signs bearing verbal messages; these measured 1.5 in (3.8 cm) on a side. The remaining three stimuli were signs bearing symbols; these measured 1.75 in (4.4 cm) on a side. Figure 7 presents the six test stimuli ranked in this study.

4.2.3 Test Conditions

For the comprehension and assimilation portions, each subject was tested on only one of the candidate warning devices evaluated in this study, identified in this section as a "target stimulus." In addition to a given target, subjects responded to three other signs serving as "distractor stimuli," which altogether made up a stimulus set of four items. Figure 8 shows the eight target and distractor stimuli sets. With a total of 256 subjects, and eight stimulus sets, each candidate warning device was evaluated by 32 individuals.

The comprehension phase of the study involved a single presentation of one candidate warning device, plus its three accompanying distractors, requiring four separate responses by a subject. The assimilation phase of the study involved four presentations of one (i.e., the same) candidate warning device and its three accompanying distractors, requiring sixteen separate responses.

To control for any possible effects on a subject's response of a sign's position in the testing sequence, the presentation order of the four signs viewed by a given subject was determined using a Latin-square ordering scheme described by the general formula 1, n, 2, n-1,...

4.2.4 Protocol

Data collection in the laboratory tests proceeded in three phases associated with, respectively, the ability of subjects to comprehend the various warning devices, to assimilate them, and to rank them. All testing was done on a one-person-at-a-time basis, and each session (including both test phases) required approximately 15 minutes for a subject to complete. In all, four test sites were used in this study -- two New Jersey vehicle inspection centers in Flemington and Cherry Hill, and two Pennsylvania drivers' license photo centers in Gutheville and Media -- to ensure a mix of urban, suburban, and

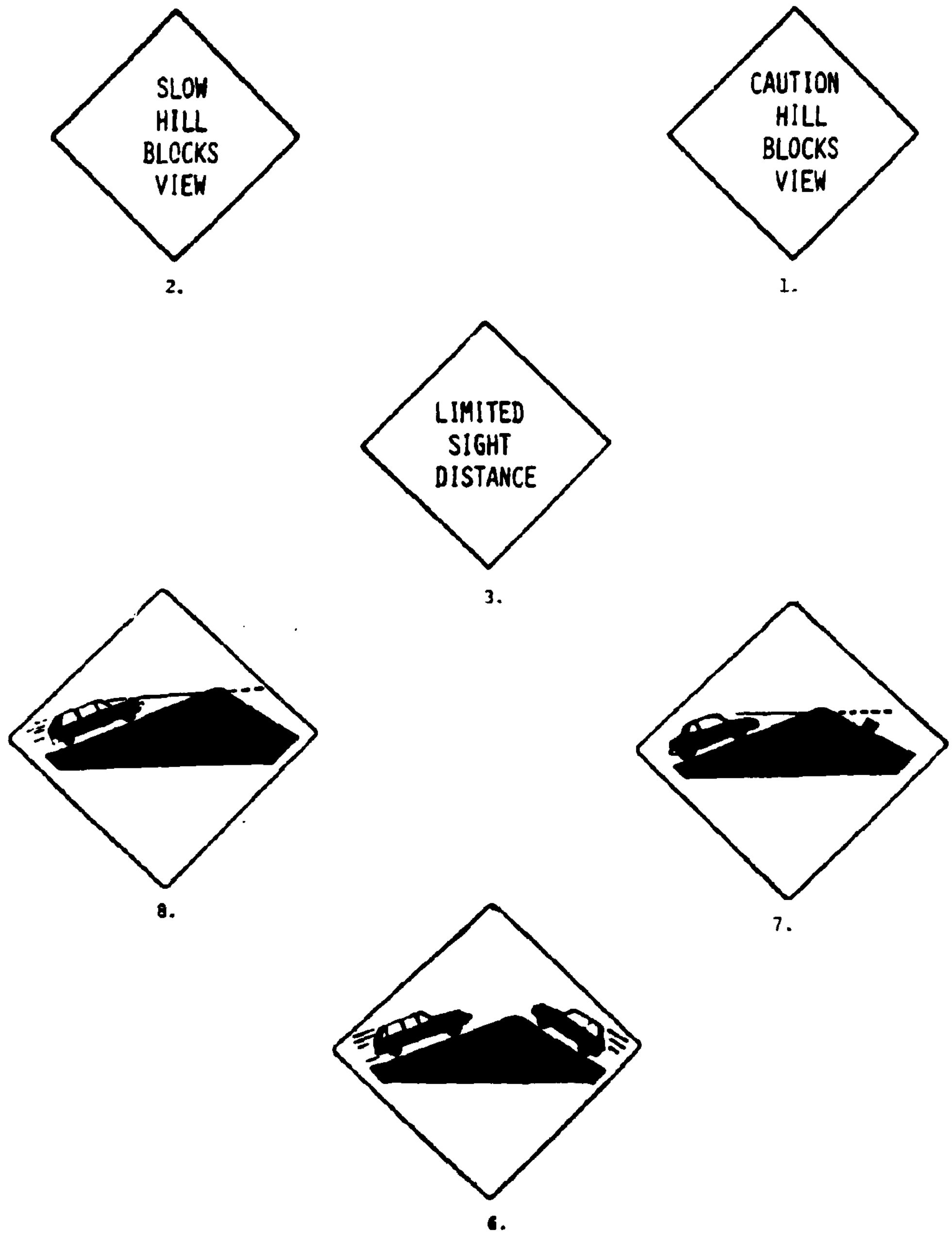


Figure 7 . Stimuli Evaluated in Preference Ranking Test

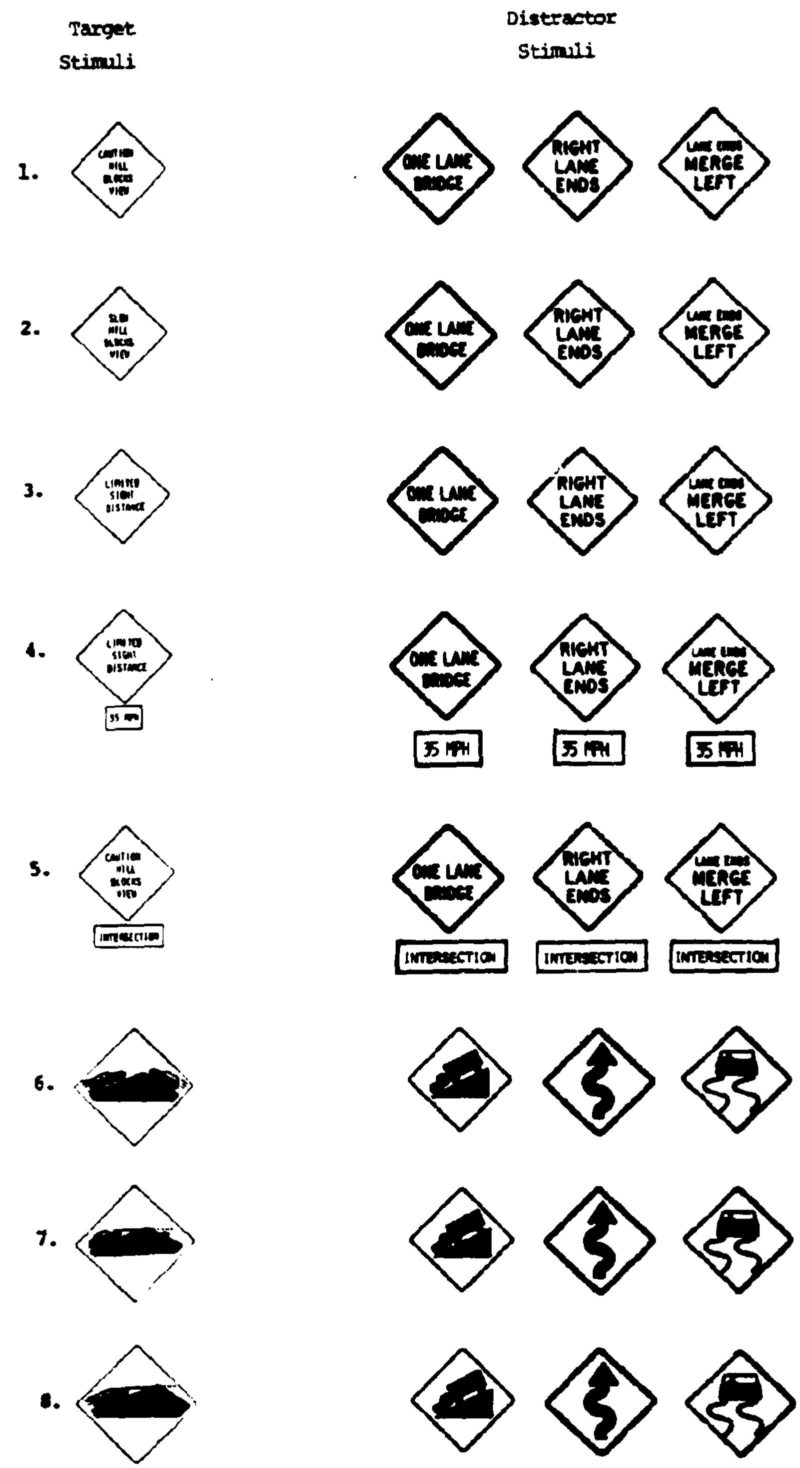


Figure 8. Stimuli Used for Comprehension and Assimilation Tests

rural dwellers in the test sample. Sixty-four subjects were run at each site using an identical protocol.

The testing took place in separate rooms (most often a supervisor's office) in which all overhead lighting was extinguished, to facilitate the viewing of the stimulus slides for the comprehension and assimilation portions. Each subject was seated so that the distance between a subject's eye and the screen was 4 ft (1.2 m). This viewing distance preserved the ratio to sign size that existed when the warning devices were photographed; that is, a sign height of 42 in (1.1 m) photographed at a distance of 85 ft (26 m) translates to a size-to-distance ratio of 1:24, the same as a 2-inch-high (5.1 cm) image of a sign viewed from a distance of 4 ft (1.2 m).

The subject's name, age, and number of years of driving experience were recorded. Next, the experimenter explained:

> "We are conducting a study on highway signs. First, I'm going to use this projector to show you several different warning signs that might be found along a highway, and I want you to explain to me what the message or picture on each sign means to you, and then tell me what you would do if you saw the sign while you were driving. You may take as much time as you need to respond."

The subject's answer regarding the meaning of the target stimulus (embedded among the three distractor stimuli) was recorded, along with the behavioral response each subject associated with the candidate warning device he/she was viewing. The experimenter immediately assigned a level of correctness to the subject's reply, by placing it in one of three categories:

1. Completely correct -- all aspects of the candidate device's intended message correctly comprehended, including the elements that a warning was being delivered involving a problem of a driver not being able to see some kind of hazard hidden out of sight over a hill, plus a description of an appropriate driver response (slow down, use caution, etc.).

2. Marginally correct -- one or more of the elements underlined above is not stated, but an appropriate driver response is described.

3. Incorrect -- intended message of candidate device is misunderstood (all elements not stated) and/or an inappropriate driver response is described (e.g., accelerate).

The experimenter then stated the intended meaning of the candidate warning device using the following standard format:

> "To warn drivers approaching a hill crest that their vision is restricted, and that particular caution is required under such conditions due to possible hazards hidden on the other side of the hill."

The experimenter then asked subjects to relate how clearly they thought the target stimulus conveyed the intended message. A ten-point bipolar scale was used for this purpose, anchored with the adjectives "very clear" and "very unclear". Subjects circled a number between one and ten (inclusive) tc indicate their response. Similarly, subjects were asked to rate -- on two additional scales -- the importance of 1) comprehending, and 2) being able to rapidly identify the message on a highway sign. Again, ten-point bipolar scales were employed, both anchored with with the adjectives "very important" and "not important at all."

Next, the experimenter delivered a set of instructions to subjects for the assimilation test. Each participant was told:

> "In this part of the study I want to see how well you can identify each of the four signs you've just been shown, when you see them for only a fraction of a second apiece. When I say 'Ready' you focus on the center of the screen, and I will trigger a very brief display of one of the signs. Please try to immediately tell me the message that was on the sign you saw. To review, here are the four alternatives. Each of the signs I am about to show you will be one of these four. Any questions?"

The experimenter then slowly displayed the four signs in turn to the subject, making sure the meaning of each was thoroughly understood.

The set of four signs (one target stimulus, three distractors) was presented to subjects at an exposure duration of 50 milliseconds. This exposure duration was selected after pilot tests indicated that near-error-free performance would be obtained with any more lengthy interval, making it impossible to detect differences between candidate warning devices in terms of subjects' ability to identify one message, versus another, at a glance.

After each response, the experimenter recorded whether the subject did or did not correctly identify the stimulus slide he was shown, then alerted the subject to get ready for the next slide.

For the ranking test, the subject was presented with the packet of three miniature verbal signs prepared on cardboard backings and asked to decide which was the best, the next best, and the worst at conveying the intended warning. The same procedure was used to rank the symbol signs.

4.3 Data Analysis

The data collected in the laboratory tests were analyzed to determine the relative effectiveness of the candidate warning devices, in terms of subjects' ability to comprehend and assimilate the messages on the signs, and according to their indicated preference for one sign over the others. Statistical tests on the various performance measures were conducted from two standpoints; one which considered all eight warning devices as one group, and another which treated signs bearing verbal -- versus symbol -- messages as two separate and distinct subgroups. Both chi-square (X^2) tests and analyses of variance (ANOVA) were employed in the data analyses.

4.3.1 Comprehension Test

Data pertaining to subjects' ability to understand the intended meaning of the candidate warning devices are depicted in Table 5. The figures shown were derived from two sources. Of primary importance was subjects' performance on the initial task in which they were asked to explain the meaning of each sign. This resulted in different numbers of completely correct (CC), marginally correct (MC), and incorrect (IC) responses associated with each candidate device.

In addition, subjects' ratings (on the ten-point scale) of how clearly the signs conveyed the intended meaning generated integer values (1 through 10) which were combined with the level-of-correctness of individuals' responses. This procedure yielded weighted comprehension scores for all subjects, which were summed and then divided by the number of individuals viewing each sign (32) to produce a mean weighted comprehension score for every candidate warning device. Specifically, each subject's weighted score could attain a maximum value of 20, when his response was either completely or marginally correct and the subject assigned the device he was shown a rating corresponding to the "very clear" anchor of the bipolar scale. The lowest possible weighted score was 1, reflecting the least desirable (i.e., potentially most hazardous) outcome in which a subject similarly rated a sign as "very clear," but totally misinterpreted its intended meaning and/or described a completely inappropriate behavioral response to the warning device.

Chi-Square Analysis

The measure of the relative frequency of CC, MC, and IC responses associated with each sign produced categorical data, which were analyzed using chi-square (X^2) tests. First, the relative effectiveness of the warning devices was evaluated at a gross level, to determine whether significant differences in the frequency of all correct responses (CC and MC combined) existed among all eight signs, considered as a single group. This analysis failed to reach significance at the .05 level, suggesting that differences in the observed frequency of (all) correct responses among the signs could have been due to chance alone. However, when the same statistical test was applied to the incorrect response data (for all eight signs), highly significant differences ($X^2 = 45.9$; d.f. = 7; $p < .001$) among the candidate devices were revealed.

A visual inspection of the figures displayed in Table 5 can explain this apparent contradiction. The significant differences in terms of incorrect responses must be attributed to the relatively poor performance levels associated with stimuli 7 and 8; the chi-square test is sensitive to the variability, or "spread" in the data, which is greatly magnified when the extreme values associated with these two signs are considered in the same analysis with the six others bunched tightly together at a substantially better (i.e., more error free) level of performance. The resulting "gap" between the two subsets of data, therefore, leads to observed (significant) differences in comprehensibility. Conversely, the data pertaining to the number of correct (CC plus MC) responses are less divergent, causing the chi-square statistic to fail to reach significance (at $p < .05$) when applied to the observed differences associated with this index of comprehensibility.

To better isolate the most effective devices, an additional chi-square test was performed which considered only those responses scored as completely correct. This analysis established that observed differences among signs were

Table 5. Results of Comprehension Test

Stimulus	Number of Correct Responses: Completely Correct	Marginally Correct	Total Correct	Number of Incorrect Responses	Mean Weighted Comprehension Score
1. CAUTION HILL BLOCKS VIEW	25	6	31	1	18.3
2. SLOW HILL BLOCKS VIEW	27	5	32	0	19.1
3. LIMITED SIGHT DISTANCE	21	8	29	3	17.7
4. LIMITED SIGHT DISTANCE AND 35MPH	15	12	27	5	15.6
5. CAUTION HILL BLOCKS VIEW AND INTER-SECTION	24	4	28	4	17.3
6. SYMBOL-TWO CARS	16	12	28	4	15.6
7. SYMBOL-ONE CAR WITH LINE OF SIGHT AND OBJECT	12	3	15	17	14.3
8. SYMBOL-ONE CAR WITH LINE OF SIGHT ONLY	4	13	17	15	12.1

significant (X^2 = 23.3; d.f. = 7; p < .005). The explanation for this finding is derived from inspecting the data pertaining to marginally correct responses. It can be be seen in the data in Table 5 that those signs associated with the highest number of completely correct responses were also associated with relatively few marginally correct responses, while those signs with fewer completely correct responses were in general associated with relatively more marginally correct responses. Including the marginally correct responses in the earlier chi-square test had restricted the "spread" in the data and prevented observed differences from reaching statistical (p < .05) significance. When the marginally correct scores were excluded, more pronounced and statistically significant differences among the eight candidate devices were revealed.

Subsequent chi-square tests were performed to analyze separately observed differences in the number of completely correct (CC) responses associated with signs bearing verbal, versus symbol, messages. For the first verbal subgroup (stimuli 1-5), these differences were shown to be not statistically significant (at p < .05). For the symbol subgroup (stimuli 6-8), however, significant differences were noted (X^2 = 7.0; d.f. = 2; p < .05). Further, separate analyses of the subgroups in terms of incorrect responses reinforced this pattern -- observed differences among signs bearing verbal messages were not significant (at p < .05), while differences among signs bearing symbol messages easily reached statistical significance (X^2 = 8.2; d.f. = 2, p < .025).

The conclusions to be drawn from the chi-square analyses of data from the laboratory tests of comprehensibility can be summarized in this manner:

1. Overall performance levels of subjects, for all eight candidate warning devices, demonstrated highly significant differences both in terms of the number of <u>completely correct</u> responses and <u>incorrect</u> responses associated with the various signs.

2. The signs bearing <u>symbol messages</u> showed <u>significant differences</u> in the ability of subjects to comprehend the intended meaning of the signs.

3. The signs bearing <u>verbal messages</u> indicated that <u>significant differences</u> did not exist in the level of comprehensibility associated with each device.

Analysis of Variance

Further analyses of the data obtained in the comprehension test took the form of a series of analyses of variance (ANOVA) performed on the weighted comprehension scores described earlier. Separate one-way ANOVAs were conducted to determine whether significant differences in the weighted scores existed as a function of age, sex, years of driving experience, and the various candidate warning devices.

To evaluate potential effects of subjects' ages, ten levels having reasonably equal cell sizes (smallest = 19, largest = 28) were designated for this variable, as follows: 16-19, 20-23, 24-26, 27-31, 32-36, 37-41, 42-47, 48-54, 54-60, over 60. No significant differences (at p < .05) in subjects' ability to understand the intended meaning of the candidate warning devices as a function of age were found for signs bearing either verbal or symbolic messages.

Three levels of the number of years of driving experience were defined: less than 12, 13-25, more than 26. Cell sizes associated with each level were 92, 81, and 83, respectively. No significant differences in the weighted comprehension scores as a function of subjects' level of driving experience were found (at p < .05) for signs bearing either verbal or symbol messages.

Similarly, scores of the 130 males versus 126 females were not significantly different (at p < .05) for signs bearing either verbal or symbol messages.

The lack of significant differences as a function of the age, driving experience, and sex variables allowed us to conclude more confidently that the variation in subjects' performance in the comprehension test was attributed to the relative effectiveness of the various candidate devices.

The ANOVAs performed on the weighted comprehension scores complement the outcomes of the chi-square tests described earlier. Significant differences were noted on this dependent measure both for those signs bearing verbal messages (F = 3.98, d.f. = 4; p < .004) and for those bearing symbol messages (F = 5.93; d.f. = 2; p < .004). Post-hoc comparisons between means within each of the subgroups of test stimuli using the Duncan Multiple Range Test (alpha level fixed at .05) were conducted to pinpoint the exact source of the significant effects demonstrated in the respective ANOVAs.

For the verbal messages, the post-hoc analysis indicated that test stimulus number 4 ("LIMITED SIGHT DISTANCE" with speed advisory panel) was significantly different (poorer performance) from stimuli 1, 2, 3, and 5. No statistically significant differences were shown to exist among the group consisting of stimuli 1, 2, 3, and 5, however.

For the signs bearing symbol messages the post-hoc analysis indicated that test stimulus number 6 was significantly different (performed better) from stimuli 7 and 8, considered either singly or together, while these latter two stimuli were shown to be not significantly different from each other.

4.3.2 Assimilation Test

Data pertaining to subjects' ability to identify the message on the various candidate warning devices following a 50 msec exposure duration are presented in Table 6, collapsed across test location and stimulus replication. The percent of total possible correct responses is derived from the 128 observations of each stimulus in the assimilation test.

Chi-square tests were performed on the entire set of eight test stimuli, and on the verbal and symbol subsets separately.

The first analysis included all eight candidate devices and revealed highly significant differences in subjects' ability to rapidly identify the various signs ($X^2 = 38.1$; d.f. = 7; $p < .001$). The data in Table 6 clearly indicate the source of this effect. The performance levels associated with stimuli 1 through 5 (verbal messages) on this task are significantly poorer than the superior performance levels associated with stimuli 6 through 8 (symbol messages). The restricted range of variability within each subgroup suggests that the overall effect is attributed to differences between categories (verbal versus symbol) of warning devices, rather than to any individual stimuli.

Separate chi-square tests on the verbal and symbol sign sets supported this conclusion. In both cases, the X^2 statistic was far below that needed to demonstrate significant differences.

4.3.3 Subjects' Attitudes Toward Highway Signs

Additional data were gathered concerning how subjects rated the importance of being able to 1) comprehend, and 2) rapidly identify the message on a highway sign. This information was used to develop a weighting scheme from which a composite comprehension/assimilation score could be formed for each subject's set of responses to each candidate warning device. Each of the 256 subjects was asked to rate, on a scale [illegible] a one to ten, how important it is to understand the meaning of the sign's message, and separately, how important it is to rapidly identify a sign whose message is well known. It was found that 93% of subjects assigned the maximum value of 10, and 98% assigned either 9 or 10, to the importance of message comprehension. Similarly, 90% of subjects chose the value of 10, and 96% chose either 9 or 10 as the scale value for the importance of rapid identification.

Analysis of variance was performed to determine the extent to which subjects differed in their opinions regarding whether comprehension was more or less important than assimilations. No significant difference was discovered; thus it was concluded that comprehension and assimilation could be equally weighted.

4.3.4 Composite Comprehension/ Assimilation Scores

The mean weighted comprehension scores and percent-correct assimilation scores for selected stimuli were combined to produce composite comprehension/assimilation scores. The results of this procedure, shown in Table 7, support the conclusion from prior analyses that test stimulus 6 -- the symbol depicting two cars -- is the most promising member of the set of signs bearing symbol messages, and establish test stimulus 2 -- slow hill blocks view -- as the superior candidate warning device among those signs bearing verbal messages.

A composite comprehension/assimilation score was formed for each subject's response to each sign as the product of the normalized weighted comprehension score and the normalized assimilation score, each of which was weighted equally according to the findings of the examination of their relative importance to motorists. The normalized assimilation score was the number of correct identifications divided by the number of trials, of which there are four.

The rank values for symbol stimuli were evaluated separately from verbal stimuli in this analysis. However, mean composite scores may be compared across sign categories. Further, only those stimuli that did not have an advisory plate (INTERSECTION, 35MPH) were evaluated.

Table 6. Results of Assimilation Test

Stimulus	Number of Correct Responses	Percent of Total Possible
1. CAUTION HILL BLOCKS VIEW	62	48
2. SLOW HILL BLOCKS VIEW	70	55
3. LIMITED SIGHT DISTANCE	49	38
4. LIMITED SIGHT DISTANCE AND 35MPH	52	41
5. CAUTION HILL BLOCKS VIEW AND INTERSECTION	60	47
6. SYMBOL-TWO CARS	93	73
7. SYMBOL-ONE CAR WITH LINE OF SIGHT AND OBJECT	99	77
8. SYMBOL-ONE CAR WITH LINE OF SIGHT ONLY	92	72

Table 7. Composite Comprehension/Assimilation Scores For Selected Test Stimuli

Stimulus	Rank Value in Terms of Best Weighted Comprehension Score	Rank Value in Terms Best Percent Correct Assimilation Score	Mean Composite Score
1. CAUTION HILL BLOCKS VIEW	.958	.873	.452
2. SLOW HILL BLOCKS VIEW	1.000	1.000	.528
3. LIMITED SIGHT DISTANCE	.927	.691	.344
6. SYMBOL-TWO CARS	1.000	.948	.575
7. SYMBOL-ONE CAR WITH LINE OF SIGHT AND OBJECT	.917	1.000	.489
8. SYMBOL-ONE CAR WITH LINE OF SIGHT ONLY	.776	.935	.442

The statistical analysis of the composite comprehension/ assimilation scores followed the three-step approach previously employed to evaluate other measures of sign effectiveness. First, data from both symbol and verbal candidates were combined in an analysis of variance. The results of this analysis indicated that significant differences were present ($F = 2.36$, $PR > F = .0418$). Post-hoc analysis revealed that the composite scores for stimuli 2 and 6 were significantly higher than that for stimulus 3 ("LIMITED SIGHT DISTANCE"). Next, separate analyses were performed for the group of verbal candidates and the set of symbol candidates. Marginally significant differences ($F = 2.63$, $PR > F = .0774$) were found, and post-hoc analysis indicated that stimulus 2 was significantly different. For symbol candidates, results were not significant ($F = 2.13$, $PR > F = .1251$), but the trend indicated in analysis of other measures -- that stimulus 6 appeared to be superior -- was supported.

4.3.5 Preference Ranking Test

Table 8 shows the number of times each stimulus was ranked in each of the possible positions. Chi-square tests indicated that respondents were not equally likely to place any of the stimuli in the most preferred positions, but instead verified a clear preference for some messages and symbols over others (X^2 symbols = 178.3, sig. at .99 confidence level for 2 d.f.). Stimulus 6 was significantly more highly ranked than other symbol candidates. Among verbal messages, however, it could only be concluded that number 3 ("LIMITED SIGHT DISTANCE") was preferred significantly less often than the other two messages.

Next, an overall index of preference was constructed to more clearly convey the preference rank of each stimulus, as shown in Table 9. The index was formed separately for symbol and verbal stimuli as the product of a rank weight (3 for best rank to 1 for worst rank) multiplied by the frequency with which each stimulus appeared in each position. The products then were summed across rankings for each stimulus. This procedure resulted in a useful measure of the collective judgment of all 256 respondents regarding the effectiveness of each symbol and verbal message.

4.4 CONCLUSIONS

The most clear-cut pattern of results is that shown in the analysis of the assimilation data: people's perception of and memory for symbols is much better than it is for words. At an exposure duration of 50 msec, subjects viewing signs bearing verbal messages could correctly identify them only slightly better than half the time they were presented. However, those who were shown signs with symbol messages responded with 75% accuracy. This finding confirms that at least one sign bearing a symbol message was justified for additional field testing.

Results of the comprehension test were used to select which of the symbol and verbal signs would be used in the field studies later in the research.

The chi-square analysis demonstrated significant differences within the symbol messages. The analysis of variance underscored this finding, and the post-hoc (Duncan) test then pinpointed test stimulus number 6 (TWO CARS) as significantly superior to the other two symbols. Based on these finds, it was therefore decided that stimulus 6 should be included in the subsequent field testing.

Evaluating differences within the subgroup of test stimuli bearing verbal messages was more difficult. The analysis of variance performed on the comprehension test data associated with these signs <u>did</u> indicate significant differences in terms of subjects' ability to understand the intended meaning of the warning devices, but subsequent post-hoc analysis identified only one stimulus (number 4 -- "LIMITED SIGHT DISTANCE" plus speed advisory panel) that could be grouped apart from the other members of this subset of stimuli as significantly less comprehensible.

Use of the composite weighted comprehension/assimilation score to evaluate the verbal messages was more useful, however. Message number 2 (SLOW HILL BLOCKS VIEW) scored marginally significantly higher than the other messages. Also message number 2 had the highest (although not significantly different) score for comprehension alone and for assimilation alone.

Finally, the preference ranking test demonstrated the statistically significant superiority of symbol candidate number 6 over other symbol candidates. That test did not, however, demonstrate that any one of the two alternate verbal messages "CAUTION HILL BLOCKS VIEW" or "SLOW HILL BLOCKS VIEW" (which were <u>both</u> significantly superior to "LIMITED SIGHT DISTANCE") was significantly better than the other. However, in evaluation of the preparatory/action elements of the two verbal alternatives, it was decided that the use of the word "slow" would be more quickly and accurately assimilated and comprehended in actual highway use, and would be more appropriate than the word "caution".

Table 8. Preference Ranking Test Results
For Selected Test Stimuli

Stimulus	Rank Frequency		
	Best	Next Best	Worst
1. CAUTION HILL BLOCKS VIEW	128	114	14
2. SLOW HILL BLOCKS VIEW	108	118	30
3. LIMITED SIGHT DISTANCE	20	24	212
6. SYMBOL-TWO CARS	186	15	55
7. SYMBOL-ONE CAR WITH LINE OF SIGHT AND OBJECT	33	85	138
8. SYMBOL-ONE CAR WITH LINE OF SIGHT ONLY	37	156	63

Table 9. Index of Weighted Preference Rankings

Stimulus	Weighted Score	% Maximum Possible Score
1. CAUTION HILL BLOCKS VIEW	626	81.5
2. SLOW HILL BLOCKS VIEW	590	76.8
3. LIMITED SIGHT DISTANCE	320	41.7
6. SYMBOL-TWO CARS	643	83.7
7. SYMBOL-ONE CAR WITH LINE OF SIGHT AND OBJECT	407	53.0
8. SYMBOL-ONE CAR WITH LINE OF SIGHT ONLY	486	63.3

Based on the results of testing and analysis, it was recommended that the following signs be further examined in an operational setting in both observational and controlled field studies:

<u>VERBAL MESSAGES</u>

SLOW HILL BLOCKS VIEW

LIMITED SIGHT DISTANCE

LIMITED SIGHT DISTANCE
plus 35 mph speed advisory

<u>SYMBOL MESSAGE</u>

TWO CARS APPROACHING
FROM OPPOSITE SIDES OF HILL

5. CONTROLLED FIELD STUDIES

5.1 Objectives and Overview

The controlled field tests were designed to measure drivers' ability to 1) notice and remember, 2) correctly interpret, and 3) respond appropriately to four candidate warning devices placed at a series of sight distance-restricted vertical curves on rural two-lane highways. Together, the measures included in the controlled field tests provide an index of effectiveness of each of the candidate limited sight distance signs -- both in comparison to traffic control devices already in place along the test route, and in relation to each other -- under real-world conditions as encountered by a representative sample of the driving population.

These goals were accomplished in two separate efforts:

a) A <u>primary</u> study focused exclusively on drivers' responses to the specific vertical curve warning signs considered in this research.

b) An <u>ancillary</u> study, with fewer participants, in which drivers' responses to <u>all</u> traffic signs encountered along the test route were examined.

5.2 Test Sites

The test sites included in the controlled field studies were four sight distance-restricted vertical curves located in a hilly region of central Montgomery County, approximately 20 miles northwest of downtown Philadelphia. The sites are distributed along a 12.6 mile route, as shown in Figures 9 and 10.

As shown in Figure 10, two of the test sites (#1 and #4) were defined by the same hill, when approached from opposite directions of travel. The other sites (2 and 3) were in two separate locations.

Elevation drawings of the four test sites are shown in Figures 11 through 13. It is the symmetrical nature of the slopes on the hill shown in Figure 11 that made it possible to locate two test sites on opposite sides of the same topographical feature; the profiles of the hills defining the other test sites, by contrast, had relatively level approaches to steep downgrades. In all cases, the length of the vertical curve was well below the value listed in the AASHTO design requirements (2) for adequate stopping sight distance (SSD). Specific information relating to test site characteristics is presented in Table 10.

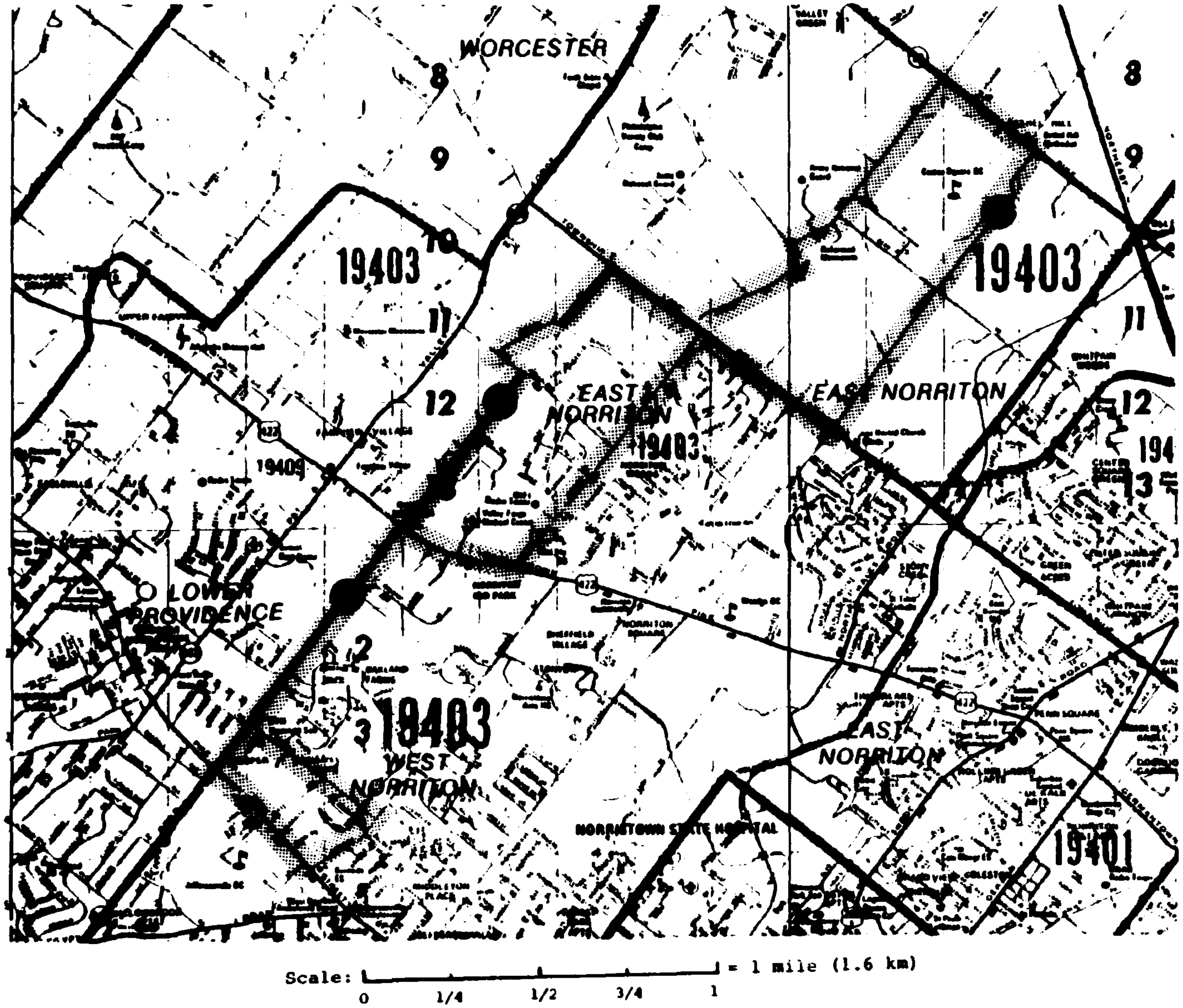


Figure 9. Location Map of Test Sites ● and Route ░ Used in Controlled Field Study

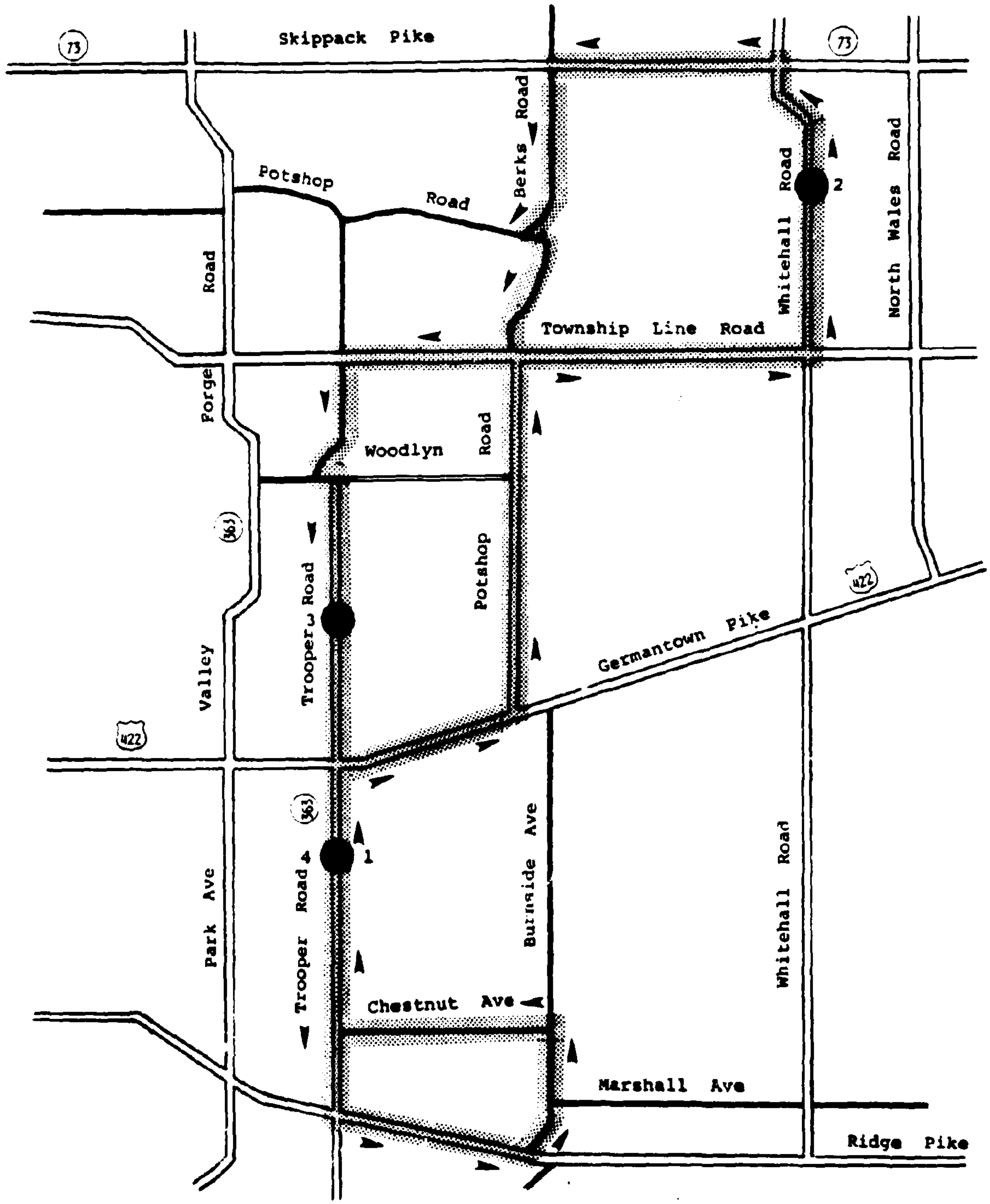


Figure 10. Simplified Map of Route Used in Controlled Field Study

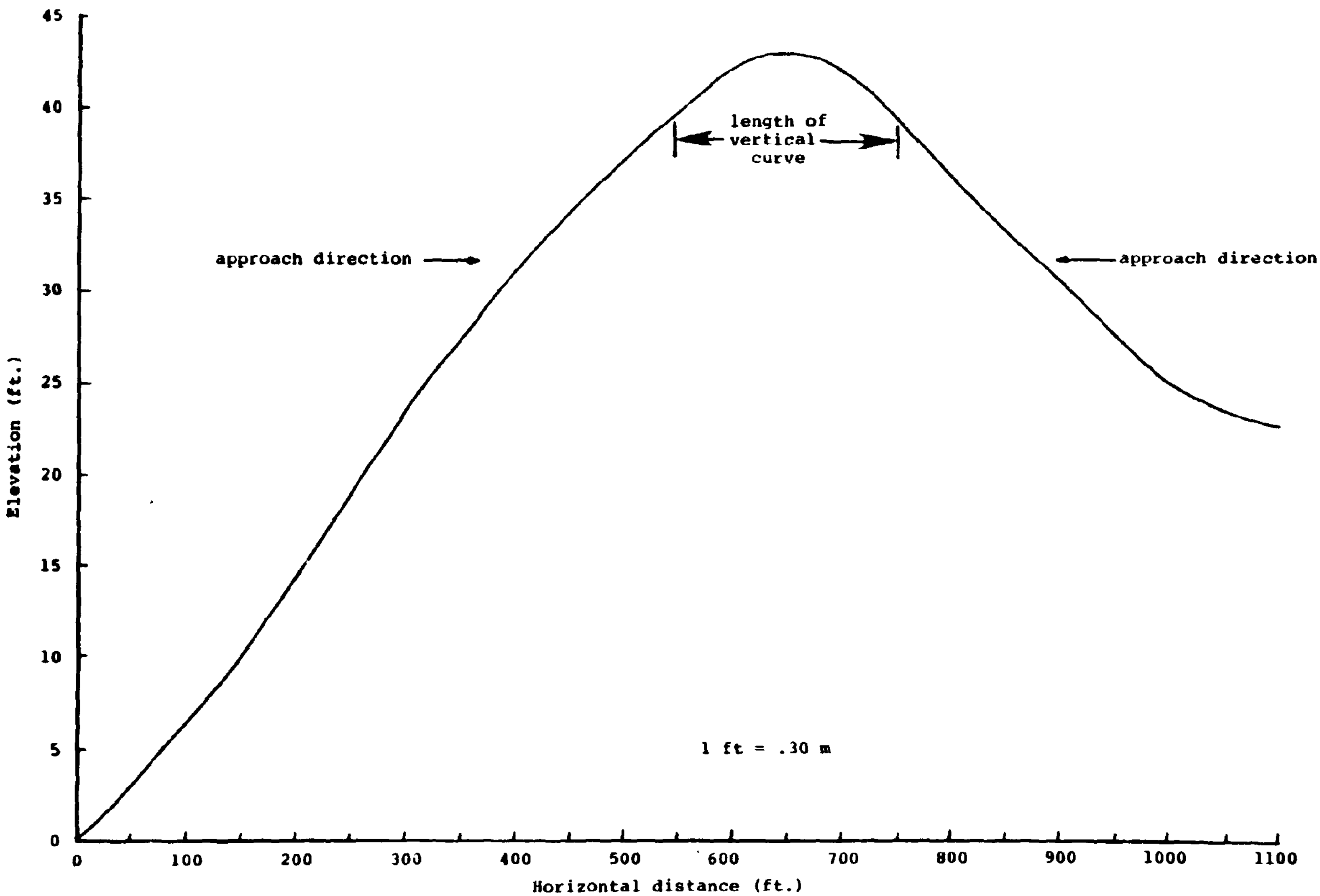


Figure 11. Vertical curve profile at Site 1 and Site 4

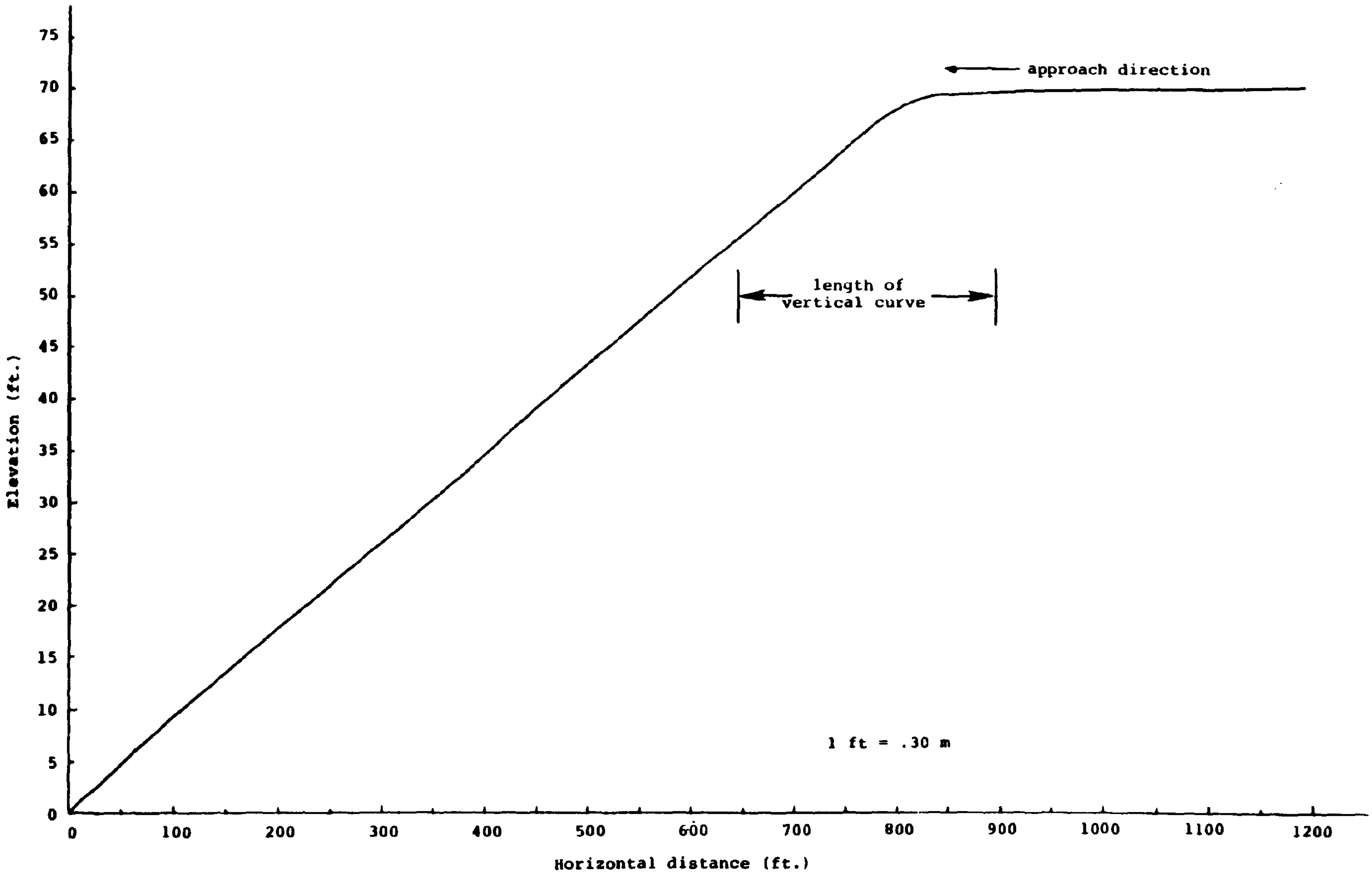


Figure 12. Vertical curve profile at Site 2

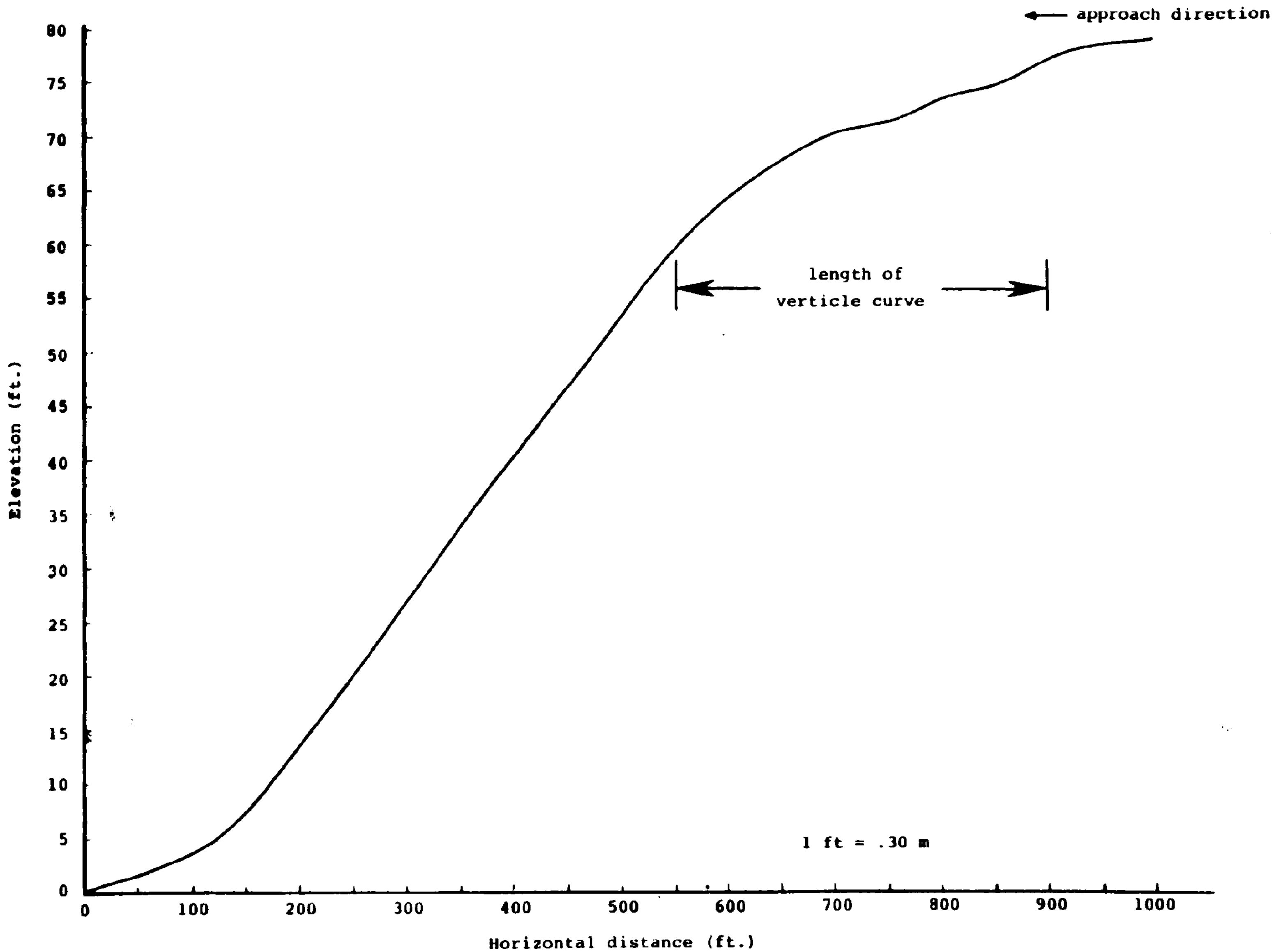


Figure 13. Vertical curve profile at Site 3

Table 10. Characteristics of Test Sites

Site Number	Length of Vertical Curve	Existing* Sight Distance	Algebraic Diff. in Grades	Average Daily Traffic (ADT)
1	200 ft	153 ft	11.9%	3,750
2	300 ft	229 ft	8.0%	2,000
3	350 ft	214 ft	10.7%	950
4	200 ft	153 ft	11.9%	3,750

*Based on detection of an object 0.5 ft above roadway surface by an observer 3.75 ft above roadway surface.

1 ft = .30 m

The roadway surface at the test sites was bituminous concrete. Shoulder width at the four sites varied from about one foot to about six feet, and in no instance were vertical curve warning devices in place at any of the sites prior to the controlled field studies. The speed limits of the test sites were 45 mph at sites 1, 2, and 4, and 40 mph at site 3. Observed (dry weather) speeds along the test route measured 43 mph (69 kph), 45 mph (72 kph), 44 mph (71 kph), and 48 mph (77 kph) at sites 1, 2, 3, and 4, respectively.

5.3 Primary Study

5.3.1 Stimulus Characteristics

Two sets of stimuli are described in this section: Target stimuli were the candidate warning devices evaluated in this study, while distractor stimuli refers to all other warning, regulatory, directional and advisory traffic control devices found along the test route. The target stimuli are shown in Figure 14.

All target stimuli consisted of black lettering (or symbols) on reflectorized yellow sheeting, on a backing of standard gauge (.080 in) aluminum. Each sign was placed at a height of at least least 5 ft (1.5 m) above the roadway surface, with a lateral clearance of 6 ft (1.8 m) or more from the roadway edge.

The distractor stimuli distributed along the test route included a total of 111 previously existing traffic control devices.

A complete breakdown of the distractor stimuli is presented in Table 11. In general, these signs were in fair to good condition; isolated signs whose visibility was judged to be significantly reduced by road grime were cleaned before the study was begun, however.

5.3.2 Test Subjects

A total of 64 subjects for this study were recruited through advertisements in suburban newspapers stating a need for licensed drivers of all ages to serve as paid participants in a highway safety research project. Potential subjects were screened to ensure that a range of ages in the sample roughly corresponded to that of the driving population, and that none were familiar with the test route.

5.3.3 Dependent Measures

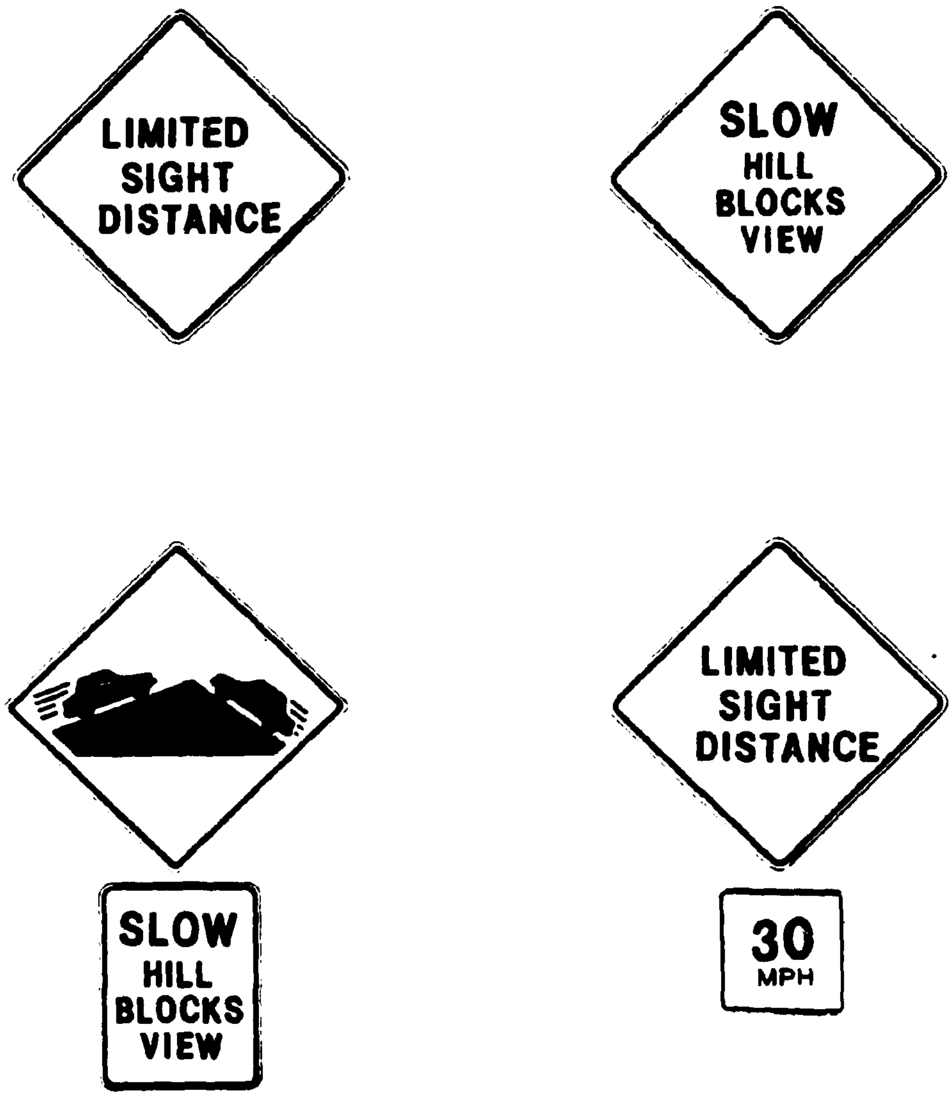
The dependent measures employed in this study were of three types -- observational data regarding driver responses to traffic control devices encountered along the test route, memory measures designed to reveal which signs were most often noticed and most correctly interpreted by test subjects, and responses to a structured post-test interview in which subjects expressed their relative preferences for the LSD devices distributed along the test route.

Driver response to traffic control devices was measured as follows: As subjects drove through the test route, the experimenter recorded the driver's behavior in response to each traffic control device encountered on the route. the experimenter noted on a checklist that included each sign in sequence on the route whether a subject a) slowed or braked in response to a device, b) made any unusual or inappropriate response to a device, c) made any remark in response to a device, d) made an overt orienting response (i.e., turned his head), and/or e) made any response to a device not covered by the preceding categories. Only positive instances of any of the above behaviors were noted. Two different memory measures were used to assess how well each subject could remember the signs distributed along the test route, as follows:

a) A free recall memory test was administered as soon as a subject had returned to the starting point on the test route. In this test the subject was asked to recall as many of the (traffic) signs he saw along the route as he could, in any order. Next, the subject was asked to explain, briefly, the meaning of each sign that he was able to recall. The experimenter noted whether each explanation was correct or incorrect, and recorded completely any incorrect responses to the candidate warning devices being evaluated in this study.

b) A recognition memory test was then administered, in which the subject was shown pictures of signs and was asked to respond "Yes" or "No" to the question, "Was this sign present along the route you just drove?" The four vertical curve warning signs were included in these pictures, plus four other warning signs also present along the route, plus an equal number (8) of warning signs not present on the test route, resulting in a total of 16 "Yes-No" responses for each subject.

With respect to the latter measure, the frequency of "Yes" responses and the percent correct -- based on the responses of all test subjects -- were calculated



Notes: Warning Signs 30 in x 30 in
SLOW HILL BLOCKS VIEW plate 18 in x 24 in
Speed advisory plate 18 in x 24 in
INTERSECTION plate 24 in x 12 in

1 in = 2.54 cm

Figure 14. Candidate Warning Devices

Table 11. Inventory of Existing Signs Along Test Route

Sign Message	Sign Category	Quantity
1. Speed limit (25, 35, 40, 45)	Regulatory	41
2. No passing zone ahead	Regulatory	9
3. Stop	Regulatory	8
4. Center lane-left turn only	Regulatory	3
5. No trucks	Regulatory	2
6. Pass with care	Regulatory	1
	Regulatory: Total = 64	
7. Watch children	Warning	13
8. Intersection ahead	Warning	7
9. Sharp curve (chevron alignment)	Warning	6
10. Turn in road ahead	Warning	4
11. Curve ahead	Warning	2
12. Road narrows	Warning	1
13. Slow	Warning	1
14. Stop ahead	Warning	1
15. Bridge abutment	Warning	1
	Warning: Total = 36	
16. End school zone	Advisory	4
17. School zone	Advisory	3
	Advisory: Total = 7	
18. Junction U.S. Route 422	Directional	2
19. West-state highway 73	Directional	1
20. Junction state highway 73	Directional	1
	Directional: Total = 4	
	All devices: Total = 111	

for the four candidate LSD devices tested in the controlled field study. Recall performance for the vertical curve warning signs was measured by both the frequency with which each device was remembered, and the number of correct and incorrect responses for the meaning of each sign.

Driver preferences for the candidate LSD devices were measured by showing each subject pictures of the four vertical curve warning signs seen on the test route, and then asking the subject to rank order them in terms of their relative effectiveness as warning devices for sight-restricted vertical curves. Frequency counts of how many times each sign was placed in each position (1, 2, 3, or 4) were compiled later.

5.3.4 Experimental Protocol

On the day before each subject was scheduled to be tested, the experimenter directed the subject to meet at a specified time at one of the four different starting points, labeled A, B, C, and D in Figure 10. In each case, subjects were given directions that enabled them to reach a starting point without traversing any part of the test route.

After meeting the subject at a landmark (school, church, restaurant, etc.) near the desired starting point, the experimenter recorded the subject's age, and seated him/her in the driver's seat behind the wheel of the test vehicle (1978 Ford Fairmont, 4 door). Instructions for the testing were then given.

When it was clear that the subject understood the task, the experimenter directed him/her to proceed from the parking lot onto the route. The direction of travel a subject followed depended on the starting point from which the route was begun (see Figure 10); among the 64 subjects participating in the controlled field study, 16 began the route traversal from each of the four starting points (A, B, C, or D) located along the route.

As the subject was driving, the experimenter recorded any positive responses to each traffic control device. At the conclusion of the drive, the experimenter administered the two memory tests.

Finally, the experimenter debriefed the subject, explained the purpose of the study, and administered the ranking test.

The presentation order of the four LSD signs was counterbalanced across test sites and subjects according to a Latin-square type of experimental design. As mentioned previously in this section, each of the four starting points on the route was used by 16 out of the total of 64 subjects, so the same number of people overall saw a given LSD sign in the first, second, third, and last position along the route. In addition, the location of the specific LSD signs was rotated among the various test sites, so that within each 16-subject group, four individuals saw a given LSD sign at test site 1, four saw it at site 2, four saw it at site 3, and four saw it at site 4. All candidate devices were thus located at the respective test sites an equal number of times, and the same number of subjects saw each sign at a given position in the four-sign sequence.

5.3.5 Results and Data Analysis

Summary of Results

Sample characteristics regarding the age and sex of participants are shown in Table 12.

The results of the recall memory test are presented in Table 13.

Recognition memory performance, expressed both in terms of the number of "Yes" responses and a percent-correct score associated with each target stimulus, is shown in Table 14.

For the preference ranking task, which followed subject debriefing, the frequency counts of how often each candidate warning sign was placed in each position -- best to worst -- are shown in Table 15. Weighted scores for the candidate devices are also included in this table, derived by multiplying the frequency count for a given position by the inverse of its rank (e.g., position 1 count X 4, position 2 count X 3, etc.) and summing across positions, for each sign.

Finally, a tally of how often each driver behavior indicated on the experimenter's checklist was observed during the test trials -- as well as a list of specific motorist comments associated with each candidate warning device -- are shown in Table 16.

Data Analysis

For the stimulus recall data presented in Table 13, a chi-square test was applied to determine whether the four candidate warning devices were equally likely to be remembered by the subjects. The computed test statistic X^2 for this comparison was 15.46, sig-

Table 12. Age and Sex Distributions of Subjects in Primary Study

Distribution by Sex	Distribution by Age		
28 males	under 20	1	
36 females	20-29	15	mean = 40
	30-39	19	
	40-49	11	median = 36.5
	50-59	7	
	60-69	11	
	70 and over	0	

Table 13. Recall Memory Performance for Target Stimuli in Primary Study

Candidate Warning Device	Total Number of Times Remembered	Correct Interpretations	Incorrect Interpretations
SYMBOL SIGN	21	7	14
SLOW-HILL BLOCKS VIEW	26	23	3
LIMITED SIGHT DISTANCE	18	13	5
LIMITED SIGHT DISTANCE-30 MPH	4	3	1

Table 14. Recognition Memory Performance for Target Stimuli in Primary Study

Candidate Warning Device	No. "Yes" Reponses	Percent Correct
SYMBOL SIGN	36	56%
SLOW-HILL BLOCKS VIEW	43	67%
LIMITED SIGHT DISTANCE	37	58%
LIMITED SIGHT DISTANCE-30 MPH	29	45%

Table 15. Preference Ranking of Candidate Warning Signs in Primary Study: Frequency Counts and Weighted Scores

	SYMBOL SIGN	SLOW-HILL BLOCKS VIEW	LIMITED SIGHT DISTANCE	LIMITED SIGHT DISTANCE-30 MPH
Position 1 (Best)	30	23	4	7
Position 2	13	24	10	17
Position 3	7	9	18	30
Position 4 (Worst)	14	8	32	10
WEIGHTED SCORES	187	190	114	149

Table 16. Driver Behavior in Response to Candidate Warning Devices Noted During Primary Study

	SYMBOL SIGN	SLOW-HILL BLOCKS VIEW	LIMITED SIGHT DISTANCE	LIMITED SIGHT DISTANCE-30 MPH
Slowing or Braking	25	22	13	21
Inappropriate Response	0	0	0	0
Makes Remark (see below)	6	5	3	6
Overt Orienting Response (eye fixation of over 2 secs)	5	2	0	1
Other	0	*1	0	0

Specific comments:

SYMBOL SIGN -- "Never saw that before"; "That should be moved farther back, it's hard to figure out"; "What was that sign about trucks on a hill . . . use lower gear?"; "What do we have here?"; "Another new sign . . . two trucks hitting head-on"; "Trying out the new signs, eh?"

SLOW-HILL BLOCKS VIEW -- "Odd, following that 45 mph sign just before it"; "Slow, hill blocks view . . . another new sign"; "Now what's that for?"; "Did you put that sign up?"; "What was that?"

LIMITED SIGHT DISTANCE -- "Limited sight distance, followed by a 40 mph sign, seems highly inappropriate"; "Never saw a sign like that before"; "Don't see what they're talking about . . . what does that mean?"

LIMITED SIGHT DISTANCE-30 MPH -- "Why this (sign) when it said 45 mph just before it?"; "Beats me . . . I have no idea what limited sight distance is"; "Never saw that sign before"; "That's a new sign . . . never saw it before"; "First time I ever saw that sign"; "What on earth did that sign mean?"

*Driver swerved across lane boundary while staring at sign.

nificant (with d.f. = 3) at $p < .01$, indicating with 99 percent certainty that real treatment effects existed between the various candidate signs. As shown in Table 13, the frequencies of recall for the symbol sign and the "SLOW HILL BLOCKS VIEW" sign were significantly greater than the very low frequency of recall for the "LIMITED SIGHT DISTANCE-30 MPH" sign.

The "Yes" and "No" recognition memory data displayed in Table 14 was numerically transformed into 1s and 0s for each subject for each candidate sign, and was then analyzed using a one-way analysis of variance. While the ANOVA technique is not commonly associated with the analysis of dichotomous data, the procedure is acceptable (28). The outcome established the existence of significant differences ($F = 3.19$; d.f. = 3, 189; $p < .05$) between signs. Approximately equal recognition performance was found for the symbol sign and the "LIMITED SIGHT DISTANCE" sign, improved performance was indicated for the "SLOW HILL BLOCKS VIEW" sign, and the poorest recognition memory performance was observed for the "LIMITED SIGHT DISTANCE-30 MPH" sign.

Ranking Test

For the ranking test, the chi-square statistic was used on several different data groupings. In one test to determine whether the candidate warning devices were equally likely to be rated "best," the computed X^2 statistic of 29.38 (d.f. = 3, $p < .01$) demonstrated a highly significant difference in the allocation of "best" rankings by test subjects. As shown by the distribution in Table 15, the symbol sign received the largest number of "best" votes, with the "SLOW HILL BLOCKS VIEW" sign a close second. A substantial gap existed between either of these signs and the two remaining alternatives. A second test focused on the frequency of placements in the top two positions and showed similar results ($X^2 = 22.94$, $p < .01$), with the "SLOW HILL BLOCKS VIEW" and symbol sign significantly more highly ranked than the two "LIMITED SIGHT DISTANCE" signs. A third test examined whether the candidate signs were equally likely to be placed in the last (worst) position. This test revealed highly significant differences among stimuli ($X^2 = 22.50$, d.f. = 3, $p < .01$), with the "limited sight distance" sign identified as the worst alternative by fully half of the participants in the test sample.

The last analysis on this data was for the weighted preference scores, also presented in Table 15. However, a chi-square test indicated strong differences among the four stimuli ($X^2 = 24.16$; d.f. = 3; $p < .01$), with the weighted scores for the symbol and "SLOW HILL BLOCKS VIEW" signs significantly higher (more strongly preferred) than the "LIMITED SIGHT DISTANCE" alternative.

5.4 Ancillary Study

5.4.1 Test Subjects

A total of 20 subjects were recruited for the ancillary study through advertisements in suburban newspapers stating a need for licensed drivers of all ages to serve as paid participants in a highway safety research project. Individuals were screened and given brief descriptions of the test procedure over the phone, precisely as described earlier for the primary study.

5.4.2 Dependent Measures

All dependent measures used in the primary study except for the preference ranking test were again employed in the ancillary study, with the following additions and modifications:

1) The recognition memory task which was performed following the drive through the test route included a presentation of all regulatory and warning signs (without duplications) along the route, defining a set of 28 target stimuli. This stimulus set, which included three of the candidate vertical curve warning signs -- the symbol sign, the "SLOW HILL BLOCKS VIEW" sign, and the "LIMITED SIGHT DISTANCE" (without speed advisory) sign -- is shown in Figure 15, labeled T1 through T28. The distractor stimuli (D1 through D28) for this task were selected from standard signs found in the MUTCD; these signs, which were matched one-for-one as closely as possible with the target stimuli on the basis of physical similarity (color, shape, number of words/figures, etc.), are pictured in Figure 16.

2) Performance on the recall memory task was tabulated for all signs remembered by test subjects after the drive, not just the candidate vertical curve warning devices.

3) Following the performance of the memory tasks, test subjects were shown pictures of the target stimuli (T1-T28) once again and were asked to interpret the meaning of each sign, one after the other. The order of presentation of the stimuli was randomized for each subject. The experimenter recorded all incorrect interpretations.

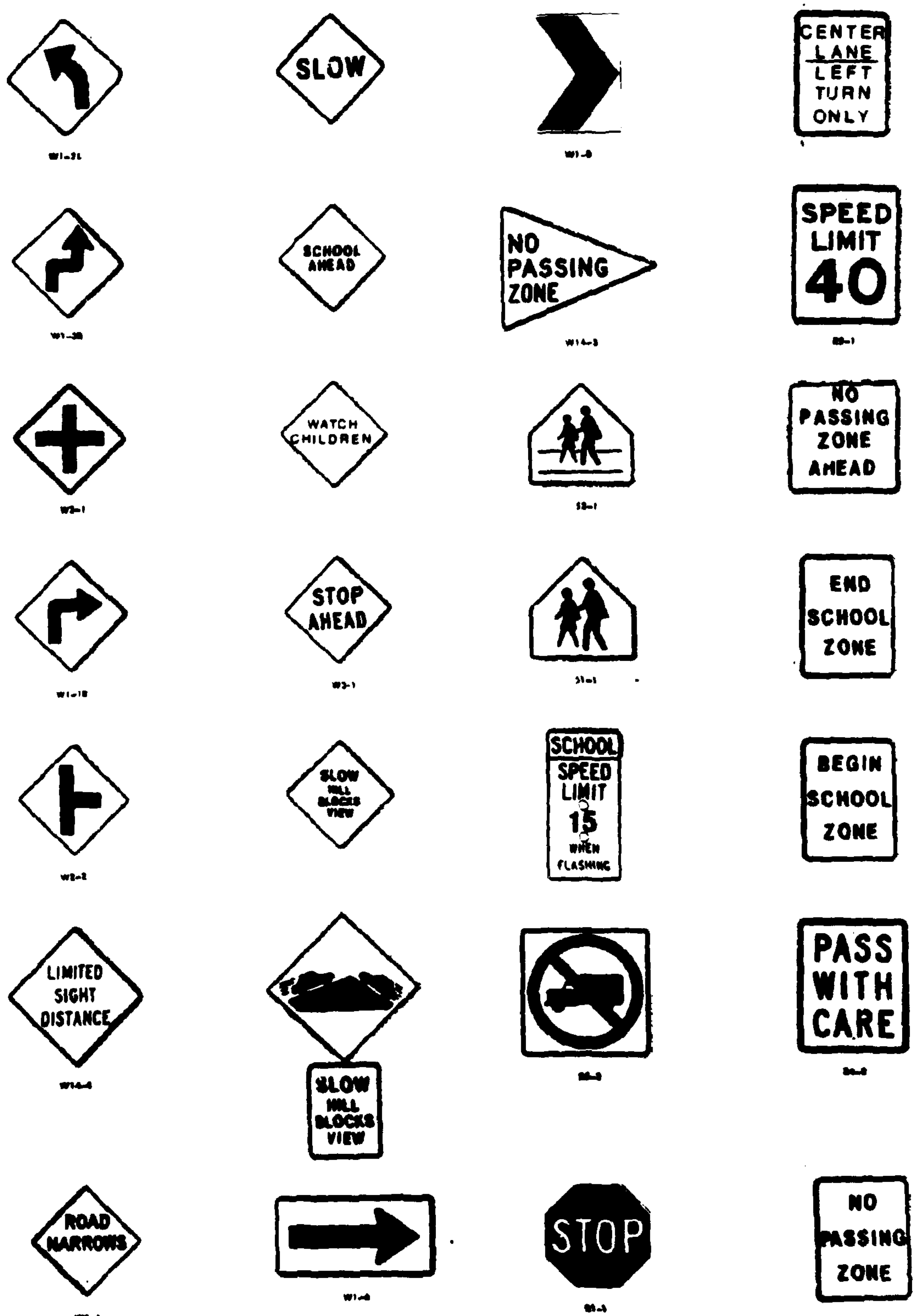


Figure 15. Target stimuli for ancillary study

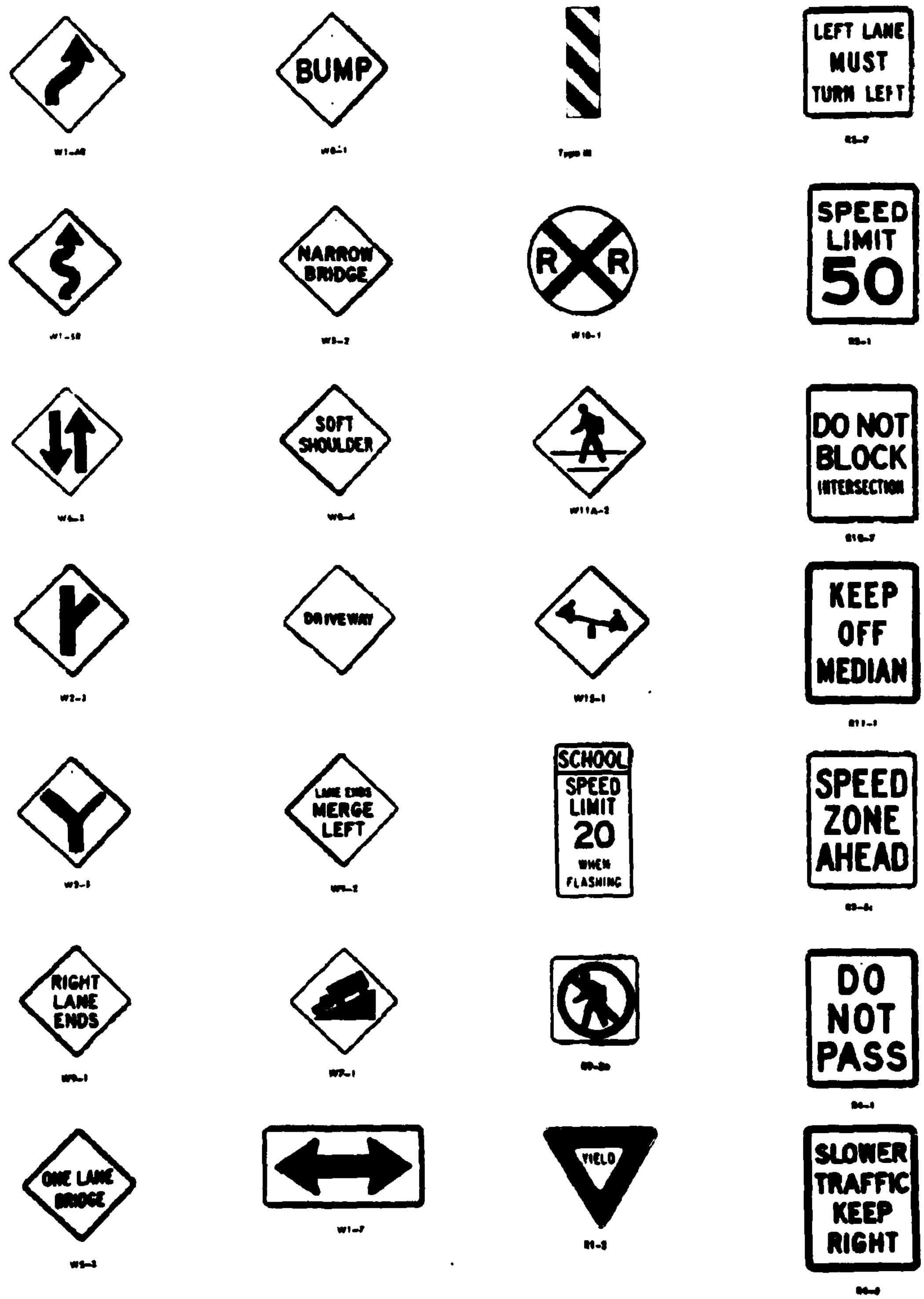


Figure 16. Distractor stimuli for ancillary study

Further, a pre-experimental interview was completed with all drivers in the ancillary study, to obtain measures of their prior level of exposure 1) to highway warning and regulatory signs, 2) to the use of flashing lights in traffic control, 3) to the use of reflector devices on or along the roadway, and 4) to roadway delineation. While these were not dependent measures (i.e., they did not reflect treatment effects of stimuli presented to subjects during the course of the drive through the test route), this information was subsequently used to help interpret the recall memory data generated in this study. The intent of the pre-experimental interview was primarily to determine the subjects' prior exposure and therefore propensity to recognize and recall certain highway signs more readily than others. The questions regarding flashing lights, reflectors, and roadway delineation were not of primary concern, but were included to distract the subjects from the central focus of the study.

5.4.3 Experimental Protocol -- Ancillary Study

After meeting the subject at the location on the test route labeled "B" in Figure 10, the experimenter recorded the subject's age, seated the subject behind the wheel of the test vehicle, and conducted a pre-experimental interview which included the following questions:

1) Please try to remember the color of each type of roadway lane marking (striping) that you have seen in your driving experience. What patterns have you seen for each color marking? What does each pattern mean?

2) What regulatory or warning signs that you have seen along the roadway in your driving experience first come to mind?

3) In what driving situations have you encountered flashing lights in the roadway environment? What was their purpose?

4) Please try to remember the different types of reflector devices you have seen along the roadway in your driving experience.

These questions were always asked, in the order shown above, so the subject's attention would not be focused upon the key item concerning prior exposure to warning and regulatory signs. On items 1, 3, and 4, any number of responses (examples) stated by subjects was accepted, up to a maximum of ten; for question 2, however, the experimenter prompted the subject to "try harder" if he was unable to generate at least five examples.

When the pre-experimental interview had been completed, the subject was given specific instructions. The experimenter then directed the subject to proceed onto the route, moving as indicated by the arrows in Figure 10. During the drive, the experimenter noted positive instances of responses to traffic control devices on the checklist, as described previously. At the conclusion of the drive, the experimenter administered the memory tests in this order:

1) recall memory for warning/regulatory signs

2) recognition memory for warning/regulatory signs

3) interpretation of the meaning of all warning/regulatory signs (including the various limited sight distance signs) along test route.

Finally, the experimenter debriefed the subject and explained the purpose of the study.

5.4.4 Results and Data Analysis -- Ancillary Study

This section describes the data obtained in this study, and the analysis techniques used to evaluate differences associated with the candidate warning signs for statistical significance.

Summary of Results

Sample characteristics regarding the age and sex of participants are presented in Table 17.

The responses of subjects on the pre-experimental interviews are shown in Tables 18 through 21.

The data obtained on the various dependent measures included in the ancillary study are presented in Tables 22 through 25. Table 22 shows the frequency of recall of signs remembered by subjects in the recall memory test conducted following the drive through the test route.

Recognition memory performance, expressed in terms of the number of "Yes" responses and a percent-correct score associated with each target stimulus, is shown in Table 23. (For key to target stimulus identification numbers, refer to Figure 15.)

Table 17. Age and Sex Distributions of Subjects in Ancillary Study

Distribution by Sex	Distribution by Age		
7 males	Under 20	0	
13 females	20-29	12	mean = 33.4
	30-39	2	
	40-49	4	median = 28.5
	50-59	1	
	60-69	1	
	70 and over	0	

Table 18. Examples of Roadway Delineation as Stated by Drivers Prior to Participation in Ancillary Study

Description (with associated meaning)	Frequency
Double yellow lines (no passing)	18
Solid yellow line with adjacent broken yellow line (no passing with solid line, passing permitted with broken line)	13
White line (roadway edge boundary)	10
Broken white line (passing permitted)	8
Broken yellow line (passing permitted)	4
White arrows on road surface (directional indicators)	4
Yellow line (roadway boundary)	3
White center line (passing permitted)	2
White line across road (stop, at intersection)	2
Separated rows of broken yellow lines in center of roadway (turns permitted from center lane)	2
Yellow center line (passing permitted)	1
Blue circle-and-wheelchair markings (handicapped use only)	1
Two adjacent sets of double yellow lines in center of roadway (median demarcation)	1
Yellow dashes on recently paved roads (meaning unknown or unstated)	1
Unspecified white line (meaning unknown or unstated)	1
Unspecified yellow line (meaning unknown or unstated)	1
Unspecified writing on road (meaning unknown or unstated)	1

Table 19. Examples of Regulatory and Warning Signs as Stated by Drivers Prior to Participation in Ancillary Study

Description	Frequency
Stop	14
Speed limit	13
School zone	11
Yield	10
Directional signs on curves	9
Pedestrian crossing	5
Railroad crossing	5
No passing zone	5
Slippery when wet	4
Stop ahead	4
Men working/work zone ahead	4
Exit (from limited-access highway)	3
Construction zone	3
Deer crossing	3
No turn on red	3
Slow	3
Lanes merge	3
Reduce speed	3
Bridge freezes before road	2
Road narrows	2
School (children) crossing	2
Do not pass	2
Left turn only	2
Fire house	2
Hill	2

Mentioned <u>once only</u> were each of the following: Watch children; Signal ahead; Truck crossing; Hidden driveway; Dangerous intersection ahead; Right lane must turn right; One lane bridge; No parking; Road floods; Pass with care; One way; Dead end; No turns; Fire lane; No U-turns; Falling rock; Hospital zone; Caution; Children at play; Intersection; Bridge clearance _ ft; Private drive; Passing zone; Emergency stop only; Route designation; No littering.

Table 20. Examples of Situations Where Flashing Lights Are Encountered as Stated by Drivers Prior to Participation in Ancillary Study

Purpose	Frequency
Warning for dangerous intersections	14
Warning for construction zones	11
Warning for dangerous curves	9
School zone warning	7
Railroad crossing warning	6
Caution	2
Warning for signal ahead	1
Marks location of fire house	1
Marks location of pedestrian crossing	1

Table 21. Examples of Reflector Devices as Stated by Drivers Prior to Participation in Ancillary Study

Description	Frequency
Double row of (embedded) yellow reflectors in center of roadway	16
Boundary posts at edge of roadway shoulder	10
(Embedded) reflectors at roadway boundary	7
Retroreflective signs above or adjacent to roadway	7
Construction site markets	4
Reflectors on posts/telephone poles near driveways	3
Median strip (?)	1

Table 22. Performance in Recall Memory Test-Ancillary Study

Sign	No. Times Remembered
Speed limit (unspecified)	18
Curve Warning Signs	14
School zone	13
Stop	12
School crossing	8
*Slow-hill blocks view	8
*Limited sight distance	8
*Symbol sign (vertical curve candidate warning device)	7
Watch children	5
No passing zone	4
**Left lane must turn left	4
Intersection	4
No trucks	3
Route designation signs	3
Slow	2
Road narrows	2
Center lane must turn left	2
**Yield	2
Pass with care	2
**Do not pass	2
End school zone	2
No parking	2

Mentioned <u>once only</u> were each of the following signs: School ahead; **Signal ahead; T-Intersection; **One way; No passing; Stop ahead; No passing zone ahead; **Do not enter.

*Denotes candidate vertical curve warning device.

**Signs included in subject's responses but not actually present along test route.

Table 23. Performance in Recognition Memory Test - Ancillary Study

Stimulus	No. "Yes" Responses	Percent Correct
T1	14	70
T2	15	75
T3	17	85
T4	13	65
T5	11	55
*T6	12	60
T7	8	40
T8	20	100
T9	13	65
T10	16	80
T11	14	70
*T12	11	55
*T13	11	55
T14	13	65
T15	13	65
T16	11	55
T17	15	75
T18	16	80
T19	19	95
T20	13	65
T21	20	100
T22	9	45
T23	19	95
T24	16	80
T25	16	80
T26	8	40
T27	7	35
T28	7	35

*Denotes candidate vertical curve warning sign.

Table 24. Interpretations of Signs Encountered Along Test Route - Ancillary Study

Sign	Correct Interpretations	Incorrect Interpretations
SYMBOL SIGN (T13) (accompanied by explanatory panel)	20	0
SLOW-HILL BLOCKS VIEW (T12)	20	0
LIMITED SIGHT DISTANCE (T6)	9	11
All other target stimuli (T1-T28, except above numbers)	20	0

Record of incorrect interpretations:

- Eight (8) subjects failed to name any cause for the condition denoted by the LIMITED SIGHT DISTANCE sign; specifically, no condition of obstructed forward vision was described.
- One (1) subject vaguely responded to the LIMITED SIGHT DISTANCE sign by stating, "Something obstructs your vision," but did not include "hill" in his response.
- One (1) subject explained that, "The driver should slow down," in response to the LIMITED SIGHT DISTANCE sign, but could not say why.
- One (1) subject explained that the LIMITED SIGHT DISTANCE sign referred to conditions of "curves or fog," omitting any reference to hills.

Table 25. Driver Responses to Candidate Warning Devices Noted During Test Trials - Ancillary Study

	SYMBOL SIGN	SLOW-HILL BLOCKS VIEW	LIMITED SIGHT DISTANCE	LIMITED SIGHT DISTANCE-30 MPH
Slowing or Braking	1	1	1	0
Inapproptiate response	0	0	0	0
Makes Remark	3	1	4	0
Overt Orienting Response	0	0	0	0
Other	*1	*1	*1	0

Specific comments:

SYMBOL SIGN -- "That sign really grabs your attention"; "Good sign . . . caught my eye"; "It's dumb to have a 40 mph sign right after that other (symbol) sign"

SLOW-HILL BLOCKS VIEW -- "That sign's good for people who don't know the road"

LIMITED SIGHT DISTANCE -- "That sign is interesting . . . I've never seen it before"; 'Limited sight distance--that's interesting"; "Limited sight distance . . . that's something new"; "Never saw that sign before . . . it's a good idea putting it up, its entertaining"

*All "other" responses consisted of subjects visibly straining their necks to see over crest of hill associated with candidate vertical warning device.

Data obtained when subjects were asked to interpret the meaning of each target stimulus (T1-T28), following the recognition memory test, are presented in Table 24.

In Table 25, those driver behaviors noted on the experimenter's checklist in response to the various vertical curve candidate warning signs are summarized.

Data Analysis

The analysis techniques employed in the search for statistically significant differences between test stimuli were dictated by the nature of the data. In this study, the dependent measures of recall and recognition memory performance, as well as the interpretability of roadway signing, are expressed solely in terms of frequency counts, for which chi-square tests are the most appropriate analysis technique. By contrast, the tally of driver responses noted on the experimenter's checklist, and the information revealed in the pre-experimental interviews are purely descriptive measures, from which conclusions were drawn by logical inference but not rigorous statistical procedures. In addition, a Pearson product-moment correlation was performed to compare the sign recall data generated in the pre-experimental interview with that from the subsequent dependent (recall) memory task.

The outcomes of the chi-square tests were largely non-significant. For performance in the recall memory test (Table 22) following the test drive, the obtained value of the X^2 statistic is only .087 (d.f. = 2), which falls far short of the criterion value of 5.99 needed to demonstrate a significant difference between the candidate vertical curve warning devices, even at the .05 level of significance. Similarly, nearly identical performance in the recognition memory task (Table 14) was observed for the candidate warning signs; this also was associated with a test statistic (X^2 = .59, d.f. = 2) which is substantially under the criterion value needed to demonstrate significant differences among stimuli.

There is a marginally significant difference demonstrated for the data relating to number of correct interpretations among the candidate warning signs (X^2 = 4.95; d.f. = 2; $p < .10$); while the level of significance may be marginal, however, an inspection of Table 24 leaves no doubt as to the source of the difference. Both the symbol sign (with accompanying explanatory panel) and the "SLOW HILL BLOCKS VIEW" sign are associated with perfect scores, while over half of the sample misinterpreted the "LIMITED SIGHT DISTANCE" alternative.

Additional chi-square analyses which incorporated data pertaining to subjects' memory for <u>all</u> signs encountered along the test route were also performed, as follows. First, for the recall memory task, extremely large and significant differences were demonstrated among the signs remembered by subjects following the test drive (X^2 = 132.7; d.f. = 29; $p < .001$). Since the candidate vertical curve warning signs are all clustered near the middle of the distribution (see again Table 13), this effect can most reasonably be attributed to the wide spread between such relatively rare signs as "no passing zone ahead" and other, more frequently occurring signs such as speed limit, school zone, or stop signs.

The recognition memory data for all signs showed a similar pattern, with all twenty subjects remembering that they had seen a stop sign along the test route, but only seven of twenty remembering that they'd seen a "no passing zone ahead" sign. However, the computed test statistic (X^2 = 28.3; d.f. = 27) was below the criterion value needed to demonstrate statistically significant differences, in this case. Accordingly, various data groupings of interest were examined, made up of subsets of the target stimuli listed in Figure 15. The only grouping among which significant differences could be demonstrated was that made up of nonyellow (i.e., non-warning) signs (X^2 = 18.7; d.f. = 9; $p < .05$); this group includes stimuli T19 through T28 in Figure 15. Both the signs associated with the highest levels of recognition (stop and speed limit) and those with the lowest levels (e.g., no passing zone ahead) are in this group. Levels of recognition for the group of (yellow) warning signs -- with and without the candidate vertical curve warning devices included -- were, by comparison, much more homogeneous, precluding any statistically significant differences among this subset of target stimuli.

Finally, a Pearson correlation of +0.86 was calculated to describe the degree of correspondence between the frequency of recall for road (warning and regulatory) signs shown in the pre-experimental interview (see Table 10) and the signs along the test route recalled by subjects after their drive (see Table 13).

5.5 Conclusions From Controlled Field Studies

The primary controlled field study clearly demonstrated that both the verbal candidate -- SLOW HILL BLOCKS VIEW -- and the symbol candidate resulted in generally superior performance by motorists.

In the controlled field setting, both the verbal candidate -- SLOW HILL BLOCKS VIEW -- and the symbol candidate sign were more frequently recalled than either the LIMITED SIGHT DISTANCE sign alone or that sign with the 30 mph speed advising panel. Further, the verbal candidate's meaning was correctly interpreted when recalled in a greater proportion of cases (88%) than any other sign. It should be noted, however, that although the symbol candidate was next to most frequently recalled, it was incorrectly interpreted twice as often as it was correctly interpreted, probably because of the driving population's unfamiliarity with the new symbol.

In the recognition memory test, the SLOW HILL BLOCKS VIEW sign was most often correctly recognized, with both the symbol and the LIMITED SIGHT DISTANCE sign (without the speed advisory) virtually tied as next most often recognized.

Both the SLOW HILL BLOCKS VIEW sign and symbol sign were greatly preferred to either of the LIMITED SIGHT DISTANCE signs in the preference ranking test. The symbol sign received the greatest number of first place votes, but also was rated worst by 14 of the subjects. Overall, the verbal candidate had only a slightly higher weighted score that the symbol sign.

The study of behavioral responses demonstrated that drivers responded most often to the symbol sign, primarily by slowing or braking. Both the SLOW HILL BLOCKS VIEW sign and the LIMITED SIGHT DISTANCE sign with a speed advisory plate produced nearly equal responses, tied for second in the frequency of responses.

Summarizing across all measures of sign performance, the SLOW HILL BLOCKS VIEW legend was associated with the best performance in three measures, performed next to best in the fourth measure, and was second best in two other measures. The symbol candidate performed best in one of the measures. In contrast, the LIMITED SIGHT DISTANCE sign, both with and without the speed advisory plate, was associated with poorer performance than either of the candidate signs in all cases but one, and performed significantly more poorly in three of the four cases.

In the ancillary study, the most frequently recalled signs, both in terms of the sign exposure measurement and of the recall memory test, included those for speed limit, curve warning, stop/yield, and school crossing/zone. It should also be noted that stop, slow, speed limit, and school crossing/zone comprised eight of the top ten signs receiving "yes" responses in the recognition memory test. Although it was not among the primary objectives of the ancillary study, it was found that the SLOW HILL BLOCKS VIEW, LIMITED SIGHT DISTANCE, and symbol signs were very nearly tied, and were all in the middle range of the frequency of responses.

6. OBSERVATIONAL FIELD STUDY

6.1 Objectives and Overview

An observational field study was conducted concurrently with the controlled field study. The purpose of the observational study was to determine the extent to which each of the four candidate limited sight distance warning signs influenced the behavior of motorists who were unalerted to the experiment. The experiments involved the observation and recording of both vehicle velocity and lateral position, as well as other indications of driver response to the signs, within a length of highway starting 1,250 ft (381 m) in advance of a vertical curve, and extending 200 ft (61 m) beyond the hill crest. Each of the signs was placed at each of three rural vertical curve locations. A total of 5,338 observations of motorists who drove past the vertical curve warning signs were analyzed.

6.2 Test Sites

Three vertical curve sites were used for the observational study. Two of the sites, located in Montgomery County, PA, were also used in the controlled field study. A description of those two sites was provided in Section 5 of this report where they were identified as sites 1 and 2.

The third vertical curve site (#5) was located in a hilly, rural area of Carbon County, PA, about 75 miles (125 km) northwest of Philadelphia, on U.S. Route 209 (Pennsylvania legislative route 164), situated in the foothills of the Appalachian Mountain chain. An elevation drawing of the route is shown in Figure 17. The available sight distance is limited to 159 ft at this location. The length of the vertical curve is 240 feet and the algebraic difference in grades is 13.22%. Those geometric conditions reduce the safe speed to 27 mph.* The roadway is characterized by full-width shoulders and a new bituminous concrete, surface. The speed limit at the site is 55 mph (90 kph) and there is a high proportion of recreational traffic. Up to 50% of the traffic has been estimated by the PennDOT district engineer to be from outside of the region.

The average daily traffic (vehicles per day in both directions) at sites 1, 2, and 5 were 3,750, 2,000, and 2,700, respectively.

*Based on detection of an object 0.5 ft above roadway surface by an observer 3.75 ft above the roadway surface.

The posted speeds of sites 1, 2, and 5 were 45 mph (72 kph), 40 mph (64 kph), and 55 mph (88 kph), respectively. The observed mean speed of traffic at site 1 was 43 mph (69 kph), as determined by spot speed measurements. Estimates of vehicle speed at sites 2 and 5 were conducted using a moving car technique. The mean speed of traffic at site 2 was 45 mph (72 kph); and the mean speed of traffic at site 5 was 55 mph (88 kph).

There were no existing traffic control devices warning of sight distance restrictions due to the vertical curve at any of the three sites.

The three vertical curve environments and associated hazards for the field study included:

- obstructed view of intersection and vehicles in queue (site 1)
- obstructed view of warning for horizontal curve ahead (site 2), and
- obstructed view of vehicle parked on shoulder beyond crest of hill (site 5).

6.3 Experimental Design and Methodology

6.3.1 Stimulus Characteristics

Four candidate warning devices (signs) were evaluated. The warning signs were 30 in x 30 in (76 cm x 76 cm) diamond shapes bearing the following messages:

- SLOW HILL BLOCKS VIEW
- LIMITED SIGHT DISTANCE
- LIMITED SIGHT DISTANCE plus advisory speed limit panel (30 MPH)
- (Candidate Symbol Sign) depicting a vehicle, on each side of hill, approaching the hill crest.

At site 1, the warning signs were supplemented by a 24 in by 12 in (61 cm x 30 cm) supplementary advisory panel (below the warning sign) with the message INTERSECTION.

The warning sign with the symbolic message was displayed with an 18 in by 24 in (17 cm x 9 cm) educational panel bearing the message SLOW HILL BLOCKS VIEW.

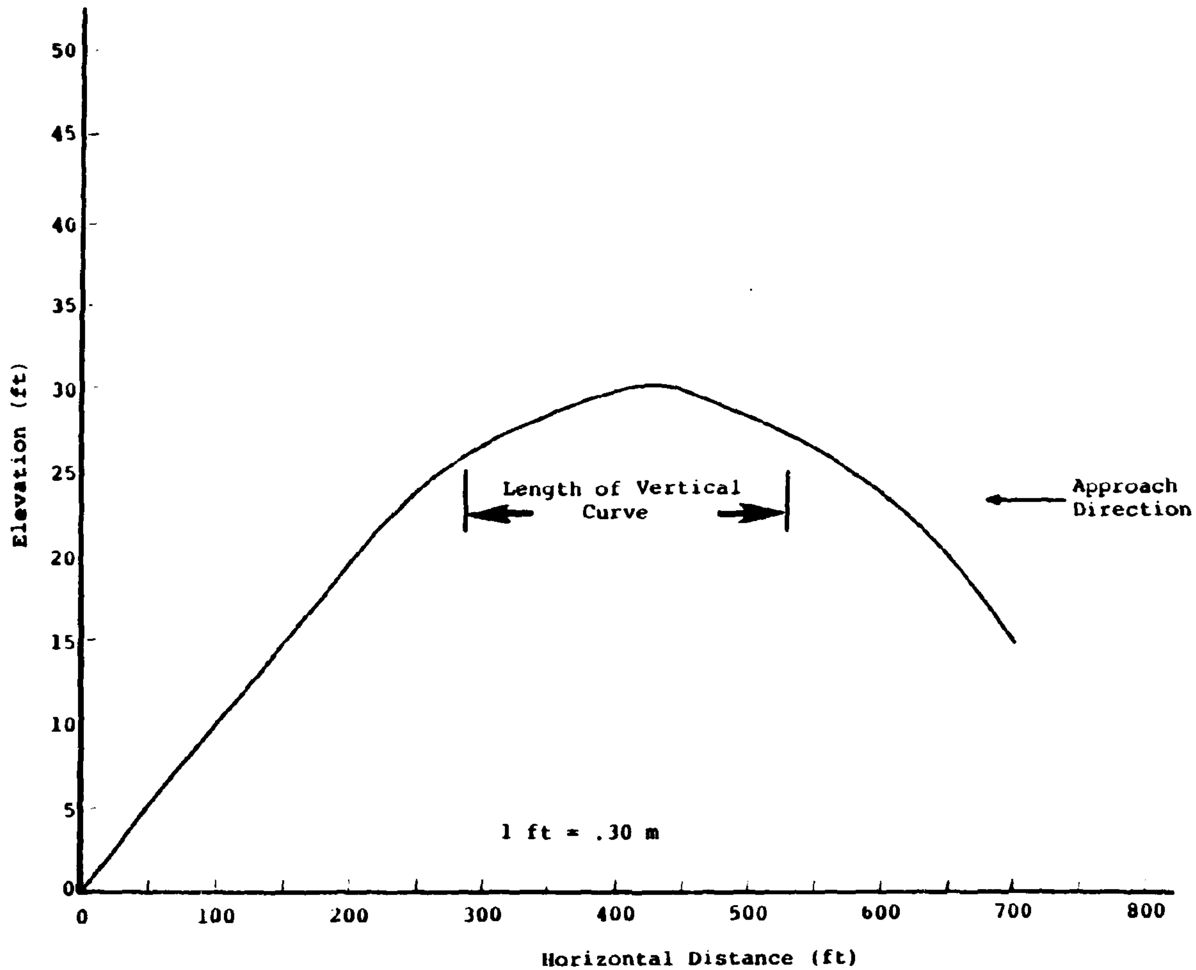


Figure 17. Vertical Curve Profile at Site 5

The candidate warning signs and their supplementary panels were previously illustrated in Figure 14 and described in Section 5.3.1.

All of the signs and panels consisted of a black border and black legend or symbol on a yellow reflectorized background, applied to a backing of standard gauge (.080 in - 2 mm) aluminum. Green channel posts, breakaway adapters, and vandal-proof bolts were used to mount the various candidate warning devices. MUTCD standards for sign lettering and placement of warning signs were observed. Each sign configuration was located as close as existing signs and terrain would allow to 750 ft (229 m) in advance of the hazard (hill crest). The height of each sign was 5 ft (1.5 m) above the roadway surface. A lateral clearance of 6 ft (1.8 m) or more from the roadway shoulder was provided. The specific conditions and sign layout at each site are depicted in Figures 18, 19, and 20.

Installation of the signs was conducted by Ketron personnel. The scheduling of installation of devices at the different test sites was staged so that data were collected at one site during an acclimation period at the other sites. Each sign was displayed at each test site for a period of seven days prior to data collection to reduce any novelty effect on local drivers.

6.3.2 Data Collection Equipment/ Instrumentation

Primary items of stimulus material included warning signs, supplementary panels, mounting hardware, and data collection apparatus. The primary data collection device was KETRON's Vehicle Trajectory Measurement System (VTMS). This is a relatively simple system which accepts inputs from tapeswitch pressure-activated ribbon-shaped switches placed at desired locations on the roadway, and prints out switch closure times accurate to the nearest millisecond. The system is designed to track one vehicle at a time through an array of road switches. When the system is reset, the system clock is set to zero and is started only when the first vehicle crosses the first switch. As the vehicle passes over each subsequent switch the clock time is printed out. All vehicles after the first are ignored until the system is manually reset.

In addition to the road switch inputs, two manual-input channels were used to record the time and nature of the occurrence of one or more driver actions that each observed vehicle may have exhibited. Activating either of the two manual input buttons caused the printer to output the time of the switch activation along with an identifying code for the manual input. With this provision, the experimenter manually recorded the occurrence and time of critical observational events including: (a) the application of brakes as indicated by the appearance of brake lights, and (b) the appearance of an opposing vehicle that might tend to externally alter the subject vehicle's trajectory. Traffic volumes in both the observed direction and the opposing direction were recorded using the volume counter inputs on the VTMS.

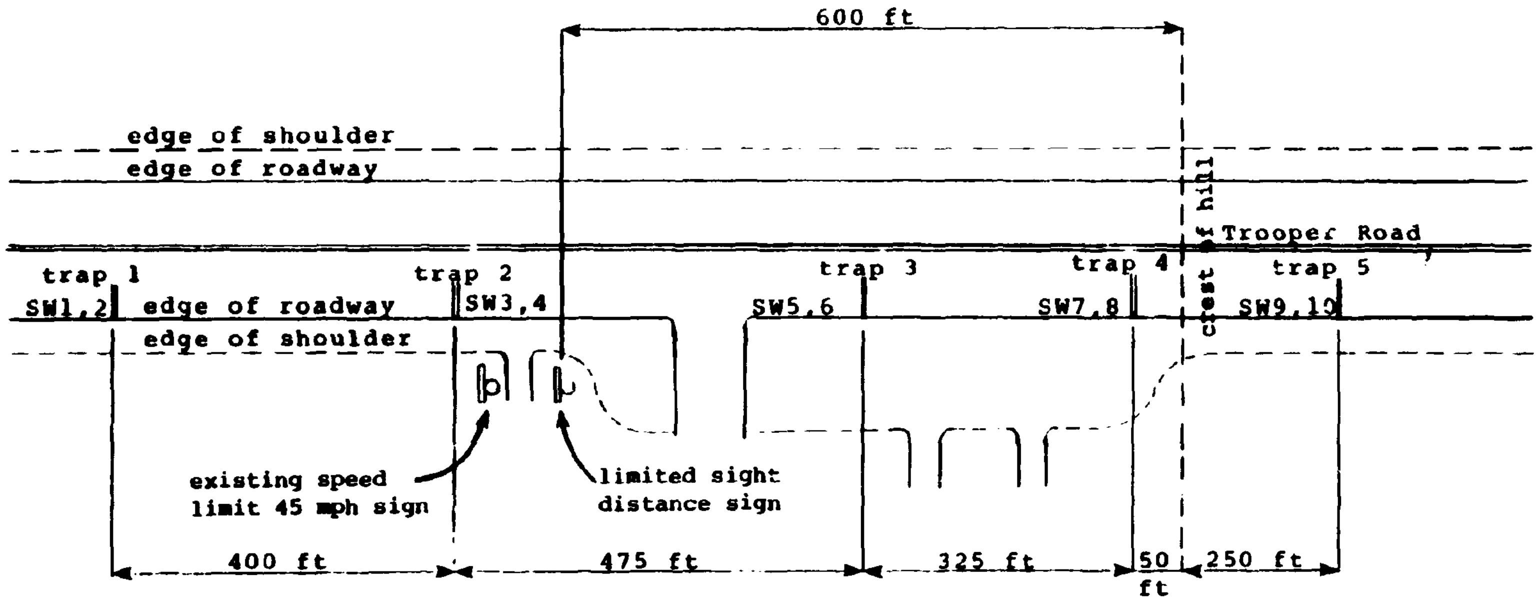
The VTMS roadway sensors utilized 3/4-inch wide tapeswitch sensors fixed to the road with double coated industrial adhesive tape and covered with special 6-inch wide duct tape. This provided a reliable bond for up to a week and resulted in a very unobtrusive installation. The sensors extended about 5ft (1.5m) into the lane from the road edge to ensure contact with the right side wheels of all vehicles. Five two-switch traps, totalling ten switches, were used at each of the installations.

The VTMS and experimenter were located off of the roadway right-of-way, either in a nearby driveway or parking area, so that they were hidden from the view of motorists in the approach under study.

Tapeswitch detectors were installed in pairs, 4 feet apart. One pair of switches, designated 1 and 2, were located 1250 ft (381 m) upstream from the hill crest, and about 500 ft (152 m) upstream of the warning devices, depending on its site specific placement. Switches 3 and 4 were placed 850 ft (259 m) upstream from the hill, which was about 100 ft (30 m) upstream of the warning device. Switches 5 and 6 were placed 375 ft (114 m) upstream of the hill crest. Switches 7 and 8 were placed 50 ft (15 m) upstream of the hill crest. The last two switches, 9 and 10, were located 200 ft (61 m) downstream from the hill crest. Tapeswitch locations and warning sign placements are shown in Figures 18, 19, and 20. The cables connecting the switches to the VTMS were run along the edge of the road, off the shoulder, to ensure that they were inconspicuous.

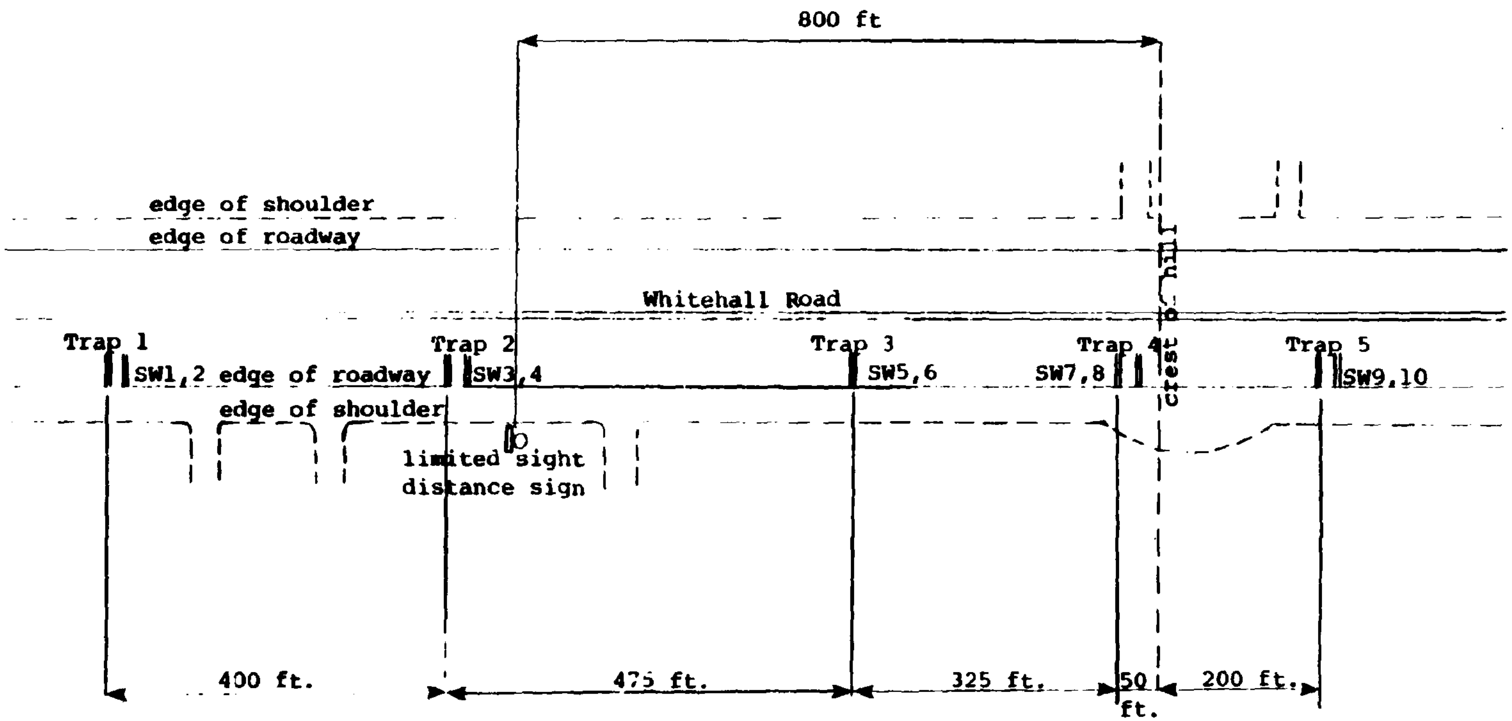
6.3.4 Dependent Measures

The dependent measures for the field study included: (a) spot velocity of vehicles, (b) position of ve-



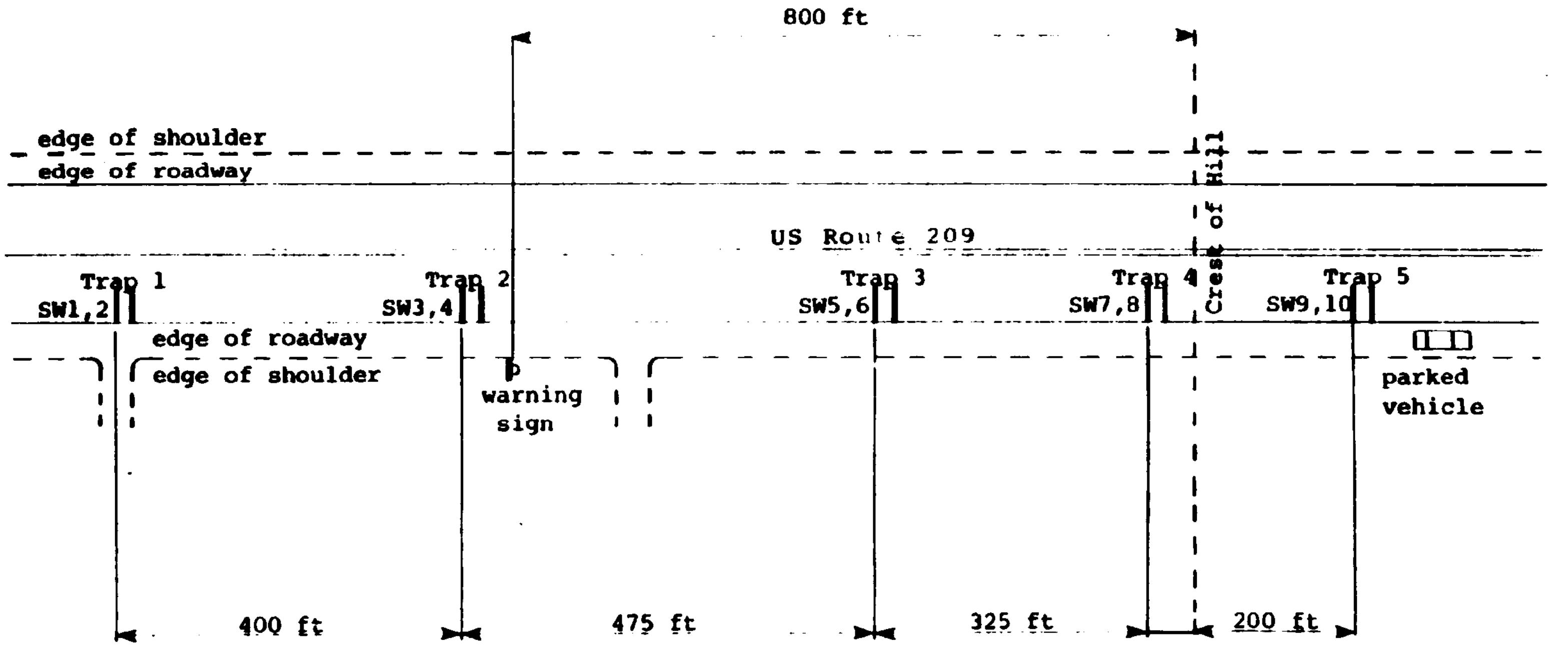
note: 1 ft = .30 m

Figure 18. Conditions and Experimental Layout at Site 1.



note: 1 ft = .30 m

Figure 19. Conditions and Experimental Layout at Site 2.



note: 1 ft = .30 m

Figure 20. Conditions and Experimental Layout at Site 5

hicles when velocity change occurs, (c) frequency of braking, and (d) frequency of other erratic behavior including slowing, drifting to the right edge of roadway, encroaching onto the shoulder, drifting to the left as far as the center line, encroaching on the opposite lane, and using high beams (night only).

Tapeswitches 1 and 2 provided a measure of the free speed of traffic prior to the signing area. These data were analyzed to determine relationships between driver free speed preference and subsequent compliance with the warning signs.

Tapeswitches 3, 4 and 7, 8 were placed to measure spot speeds at the point at which a vehicle was likely to show a speed change due to perception of the warning sign and the hill crest, respectively. Because the warning device was located as close to the MUTCD recommended distance for warning signs of 750 ft (229 m) upstream from the hazard (hill crest), the distance between tapeswitches 3, 4 and 7, 8 was fixed at 800 ft (244 m). It was believed likely that some drivers would slow down and speed up again in this distance, however. With only tapeswitches 3, 4 and 7,8, this would not be detectable. Tapeswitches 5,6 were included at the midpoint to detect such behavior.

Tapeswitches 9, 10 were included to measure the vehicle's free speed attained after the hazard had been encountered and passed. For site 5, this pair also provided the speed data that described deceleration and braking behavior when the experimenter-placed vehicle that was hidden from the view of the observed motorist by the crest of the hill was encountered.

6.3.5 Sample Size Requirements

The number of observations of vehicles passing through the instrumented section of roadway was determined by the desired precision of the estimate of the mean speed of the sample population, the desired confidence level, and knowledge of the standard deviation of the speed of vehicles at the sites, without the presence of the candidate signs. According to the Central Limit Theorem (law of large numbers) sample size may be estimated using the following relationship:

$$n = \left(\frac{Z_{\alpha/2}\,\sigma}{\bar{X} - \mu}\right)^2$$

where n = sample size

$Z_{\alpha/2}$ = confidence level (e.g., 1.96 for 95% two-tailed test)

σ = standard deviation of speed at sites (measured during base data collection)

$\bar{X} - \mu$ = precision of measurement, or difference between population mean and sample mean

The preliminary spot speed studies at the test sites yielded a standard deviation of 2.89 mph (4.82 kph) Using a 95% confidence level and a precision of 0.5 mph (0.8 kph), 128 observations were required. The selection of a precision level corresponds to the physical significance that may be placed on the difference between the effectiveness measures across two or more stimuli. More specifically, a very large sample size could lead to the conclusion that a 0.1 mph (0.2 kph) difference between the mean speed of vehicles encountering sign A versus sign B is significant. However, in a real-world sense, the 0.1 mph (0.2 kph) difference means nothing operationally. We therefore set our level of precision at 0.5 mph (0.8 kph), in which case a minimum sample size of 128 was required for each cell of the experimental matrix.

6.3.6 Experimental Design

The formal experimental design was defined by the treatments (signs), sites, and conditions under which data collection would take place and on which analysis would be performed.

The primary concern of the research was to determine whether differences in motorist behavior could be attributed to differences between warning devices. Therefore, one dimension of the experimental matrix contained a no-sign condition and the four limited sight distance warning devices, which represented the single independent variable.

A second concern was whether the presence of vehicles approaching from the opposite direction as the observed vehicle would have an influence on motorist behavior. This condition was used as a blocking variable to divide data into two sets -- not opposed and opposed. Conclusions regarding sign effectiveness would be summarized for each group of observations but no comparisons would be made between groups.

A third parameter -- sites -- was not incorporated into the experimental matrix as an independent variable because it was not desired to determine whether differences in behavioral measures were attributable to site differences. Therefore, comparisons of sign performance were made within site only, and the three site represented another blocking factor.

It was also of interest to determine whether the sign that would be found most effective during daylight conditions be would the same sign found most effective under nighttime conditions. The nighttime performance of each warning device was of lesser interest than the comparison of performance across sign type, however, thus only a limited number of nighttime observations were made at site 5 only.

Because it had been previously shown by Lyles (14) that the behavior of motorists in the vicinity of warning signs was significantly influenced by the visible presence of the hazard that caused the need for the sign, it was also decided to examine whether such a situation would influence the relative effectiveness of the candidate warning devices in this study. Therefore, one experimental condition required the placement of a parked vehicle on the shoulder of the roadway, downstream from the crest of the hill. That placement caused the view of the parked vehicle to be obstructed until the subject vehicles were approximately 100 ft (30 m) upstream from the hill crest. This condition was examined only at site 5, during both daylight and darkness, only for the no sign, LSD, and symbol alternatives, and was treated as an additional blocking variable.

The experimental matrix was therefore characterized by five treatment types by two traffic opposition conditions, repeated at sites 1, 2, and 5 without a parked car on the shoulder, and at site 5 only with a parked car on the shoulder. A partial matrix of only three treatment conditions by two traffic opposition conditions defined the experiments at site 5 at night both with and without a parked vehicle.

6.3.7 Experimental Procedures

Activities at each of the test sites included deployment of the roadway sensors immediately prior to the beginning of a data collection period at a site, daily data collection, and system monitoring. Data collection continued for a maximum of two days for each sign condition at each of the three sites, and for a maximum of two nights at one of the sites. Data collection for each sign condition followed a one-week period provided to enable local drivers to become accustomed to the sign, which minimized any novelty effect.

Following installation of the tapeswitches on the roadway, connection of all cables, and system checkout, data collection commenced. One observer was located at the VTMS to operate the system. Another observer was positioned well upstream of the vertical curve to observe and input the occurrences of brake applications and erratic behavior that occurred upstream of the observer at the VTMS.

The observers' tasks included the following:

1. Monitor the system to ensure that it was operating properly;
2. Operate the VTMS so that only isolated or lead vehicles in a platoon were recorded;
3. Observe, log, and mark the record of each sampled vehicle as well as note any unusual events;
4. Mark the occurrence of brake applications as subject drivers crest the hill (especially at site 5, where the drivers noticed the vehicle parked on the shoulders);
5. Mark the onset of opposing or oncoming vehicles coinciding with the subject vehicles approaching the hill crest;
6. Mark invalid trials; and
7. Keep additional records on traffic volume, weather conditions, time of day, and unusual events that may affect driver behavior.

6.4 Results and Data Analysis

6.4.1 Summary of Results

A complete summary of the trajectory information derived from the observational study is shown in Tables 26 and 27. There were more than 3,200 observations of unopposed vehicles, and over 2,100 observations of vehicles that faced opposing traffic. The mean velocity and standard deviation of velocity at each of the five measurement locations are shown in the tables for the group of observations associated with each candidate warning device at each site.

Frequency counts of the four types of observed driver actions associated with each warning device at each site are summarized in Tables 28, 29, 30, and 31. Brake applications were relatively frequently observed at site 2, and were also seen frequently at site 5 during both daylight and darkness when the parked vehicle was present. Observed vehicles very frequently drifted to the right at site 1, and were somewhat less frequently noted at site 2 and site 5 (day-with car). Right shoulder encroachments were only rarely noted at site 1, while vehicles drifting to the left were more often observed at site 2 and site 5.

6.4.2 Data Analysis

It can be readily seen that for data from any of the five velocity measurements locations (Traps 1-5) the velocity difference between the fastest group and the slowest group of observations for any site, condition and treatment set was rarely more than about one-half the value of the standard deviation for any of the treatment groups in that set. The within-group velocity spread only exceeded the lowest standard deviation in the two night conditions at site 5 for opposed observations, where the number of observations was less than the number required for the accurate estimation of velocity differences. It was therefore concluded that the measure of effectiveness based on velocity at each trap would not be of value in seeking statistically or operationally significant differences between the performance of the set of warning devices used at each location. That is, it was clear that no limited sight distance warning device or group of devices emerged as superior to any other device with respect to causing drivers to adjust the measured velocity of their vehicle in the vicinity of the vertical curves under study.

Similarly, the evaluation of the effect of each candidate warning device on the change in vehicular speed could not be shown to be either statistically significant or operationally significant. These measures, listed in Tables 32 and 33, rarely demonstrate a speed of more than 1.5 ft/sec (1.6 kph) between the group of vehicles having the greatest velocity and those having the smallest velocity change. Further, there is no consistent relationship between speed reduction and warning device either within site/condition across traps or within trap across sites. It could only be concluded that for the vehicles analyzed, the velocity and velocity change variables were not sufficiently sensitive to the effects that each of the warning devices had on driver behavior.

Chi-square analyses were performed on the frequency counts of behavioral data to determine whether particular warning devices could be associated with significantly different proportions of drivers who exhibited those behavioral attributes. The level of statistical certainty of the findings are shown in Tables 28, 29, 30, and 31. Because of the nature of chi-square analysis, which requires at least 6 observations in each cell, analysis was not performed on data sets having fewer observations than the minimum. In some cases, observations associated with two or more warning devices were combined to facilitate statistical analysis.

Concerning the brake application behavioral attribute, marginal statistical significance (= .10) was found at site 2 during daylight and site 5 during daylight, with and without the parked vehicle on the shoulder. At site 2, when observations of both opposed and unopposed vehicles were combined, both the baseline (no sign) condition and the SHBV sign had fewer brakers than would be expected due to chance alone, while the LSD and the LSD+30 signs had more than the expected proportions of brakers. Conversely, at site 5 during the daylight without the parked vehicle, the SHBV sign was associated with more brakers than expected, while all other treatments combined had fewer than would be expected. When the parked car was present, both the SHBV and the LSD+30 warning devices were associated with more than their expected shares of brakers among unopposed motorists, while the baseline and LSD treatments had fewer brakers than expected.

The frequency of vehicles that deviated from the center of their lane

Table 26. Summary of Observational Field Study Velocity Data - Vehicles Not Opposed

Site/Condition and Treatment	Sample Size	Average Hourly Volume	Measured Velocity (ft./sec.) Trap 1 Mean	Trap 1 SD	Trap 2 Mean	Trap 2 SD	Trap 3 Mean	Trap 3 SD	Trap 4 Mean	Trap 4 SD	Trap 5 Mean	Trap 5 SD
1/Day w/o Car												
NONE	122	281	66.0	7.4	63.6	6.9	60.1	6.6	56.8	5.7	59.7	5.8
LSD	124	310	67.4	7.0	65.0	7.0	61.3	7.5	57.6	7.0	59.8	6.6
LSD + 30	133	331	67.1	7.6	64.8	7.9	61.4	7.7	57.1	8.0	60.5	7.3
SHBV	129	242	67.1	7.7	65.0	7.8	61.8	8.1	57.7	7.5	60.6	7.3
SYMBOL	140	237	70.0	8.0	66.9	7.7	63.6	8.1	58.8	6.5	61.3	6.5
2/Day w/o Car												
NONE	197	130	66.5	8.2	58.1	8.1	60.0	7.9	59.5	8.1	59.3	7.2
LSD	152	130	66.8	8.2	57.9	8.3	59.0	7.3	58.5	7.6	58.2	8.[illegible]
LSD + 30	157	116	67.0	7.8	56.7	7.8	59.6	7.3	59.0	7.3	58.7	7.4
SHBV	182	138	67.1	9.4	57.9	9.2	59.4	8.1	59.1	8.4	58.5	8.3
SYMBOL	151	109	67.6	7.4	58.7	8.1	60.5	7.1	60.0	7.7	59.3	7.1
5/Day w/o Car												
NONE	133	124	73.1	7.2	75.9	6.6	77.0	6.4	71.4	6.5	71.8	6.1
LSD	138	140	72.4	6.7	74.6	6.4	75.2	7.8	69.4	8.4	69.9	7.8
LSD + 30	151	154	72.9	7.1	75.6	6.8	76.4	7.2	71.3	7.5	71.6	7.4
SHBV	161	144	72.2	7.4	74.5	6.8	75.1	6.9	69.6	7.3	69.8	6.8
SYMBOL	123	116	72.0	6.6	74.2	7.5	74.8	7.5	70.3	7.5	70.5	7.4
5/Day w/ Car												
NONE	163	113	71.2	7.3	73.8	7.2	74.9	7.2	69.0	7.3	68.5	6.7
LSD	162	156	73.0	7.3	75.5	6.9	76.6	7.3	71.6	6.9	70.4	6.5
LSD + 30	134	132	71.8	7.7	73.8	8.1	75.5	6.7	70.0	7.2	68.2	7.0
SHBV	126	130	72.7	7.1	74.3	6.4	74.9	6.9	70.1	7.1	68.6	6.8
SYMBOL	124	148	72.2	6.1	74.3	6.4	75.3	6.7	70.0	7.1	68.5	6.8
5/Night w/o Car												
NONE	36	73	71.7	6.3	74.5	6.4	75.3	6.2	68.4	8.3	70.4	5.9
LSD	52	107	69.2	7.8	71.8	7.4	71.7	9.4	67.5	7.2	68.6	6.6
SYMBOL	37	88	68.1	8.9	70.4	8.8	72.8	7.4	68.3	8.1	69.4	7.8
5/Night w/ Car												
NONE	63	81	71.7	9.5	73.8	8.3	74.8	8.9	69.1	9.1	68.5	8.4
LSD	58	114	72.6	8.2	74.5	10.1	74.8	10.3	70.6	9.2	69.5	8.3
SYMBOL	59	77	66.0	8.7	68.7	9.9	70.1	8.5	64.6	9.8	64.8	9.3

1 ft/sec = .30 m/sec

Table 27. Summary of Observational Field Study Velocity Data - Opposed Vehicles

Site/Condition and Treatment	Sample Size	Average Hourly Volume	Measured Velocity (ft./sec.) Trap 1 Mean	Trap 1 SD	Trap 2 Mean	Trap 2 SD	Trap 3 Mean	Trap 3 SD	Trap 4 Mean	Trap 4 SD	Trap 5 Mean	Trap 5 SD
1/Day w/o Car												
NONE	126	362	65.2	7.2	63.2	6.3	60.3	6.7	56.1	6.4	59.0	6.3
LSD	135	261	67.3	7.9	64.7	7.5	60.4	8.2	56.0	7.5	59.3	7.3
LSD + 30	143	259	67.5	8.1	64.5	7.8	60.4	8.4	56.0	7.9	60.0	6.9
SHBV	133	287	68.7	7.6	65.8	7.5	62.1	8.4	57.4	7.5	60.6	7.5
SYMBOL	147	277	68.0	7.6	64.5	8.1	61.5	8.3	56.5	7.2	59.6	5.9
2/Day w/o Car												
NONE	124	117	66.8	8.1	58.2	8.0	59.6	7.1	58.4	7.9	58.1	6.7
LSD	134	114	66.8	7.4	58.1	7.6	58.6	7.2	57.7	7.2	57.3	6.6
LSD + 30	130	114	67.0	7.9	57.6	8.6	58.8	7.9	57.9	8.1	57.3	7.6
SHBV	129	122	66.3	7.3	56.7	7.9	58.7	7.2	58.4	7.4	58.4	7.2
SYMBOL	126	145	66.3	7.0	56.9	7.8	59.1	6.6	58.2	7.7	57.6	8.5
5/Day w/o Car												
NONE	61	122	72.5	7.8	74.9	7.3	75.8	7.7	70.4	7.8	71.2	7.2
LSD	73	111	73.7	8.6	75.1	8.2	76.0	8.3	69.7	9.2	69.7	8.2
LSD + 30	75	154	69.8	8.3	72.5	7.1	73.5	7.4	68.4	7.0	69.0	6.8
SHBV	76	124	72.4	7.3	74.5	6.8	74.7	7.0	68.9	8.8	69.0	9.3
SYMBOL	78	208	72.3	7.1	74.5	6.3	75.2	6.3	69.8	7.1	69.6	8.3
5/Day w/ Car												
NONE	69	120	70.4	6.5	73.1	6.6	73.8	6.8	67.5	6.8	66.5	6.5
LSD	90	136	71.6	8.5	74.8	7.1	75.7	7.2	70.4	8.5	69.6	7.1
LSD + 30	79	131	72.5	7.4	74.8	6.2	75.3	6.3	69.6	7.2	67.9	7.1
SHBV	75	166	71.0	7.7	73.5	7.5	74.2	7.7	69.0	7.7	67.8	7.0
SYMBOL	63	144	72.5	8.1	74.6	7.2	75.0	7.6	69.7	8.1	68.3	8.3
5/Night w/o Car												
NONE	9	73	70.1	7.3	73.2	6.7	73.1	6.9	68.4	6.5	70.7	7.1
LSD	6	110	71.9	7.0	74.3	4.4	75.3	1.7	68.8	2.2	71.3	2.3
SYMBOL	18	102	65.6	8.4	67.7	7.5	69.5	7.1	65.6	8.0	66.2	6.1
5/Night w/ Car												
NONE	13	102	72.4	7.8	74.8	6.9	74.6	7.1	70.5	7.6	69.8	8.5
LSD	6	134	76.4	8.4	79.2	8.9	78.6	6.9	74.3	5.8	72.5	5.7
SYMBOL	13	90	66.4	12.3	69.1	11.8	70.0	11.2	65.5	12.8	64.6	11.2

1 ft/sec = .30 m/sec

Table 28. Summary of Observational Study Behavior Data for Brake Applications

Site/Condition	Treatment	Sample Size			Brake Application		
		Not Opposed	Opposed	Total	Not Opposed	Opposed	Total
1/Day w/o Car	NONE	122	126	248	1	3	4
	LSD	124	135	259	2	3	5
	SHBV	129	133	262	2	4	6
	SYMBOL	140	147	287	3	0	3
	LSD+30	133	143	276	1	1	2
X2 Significance					n/t	n/t	not
2/Day w/o Car	NONE	197	124	321	58	46	104
	LSD	152	134	286	58	56	114
	SHBV	182	129	311	54	41	95
	SYMBOL	151	126	277	52	44	96
	LSD+30	157	130	287	66	55	121
X2 Significance					not	not	.10
5/Day w/o Car	NONE	133	61	194	3	1	*4
	LSD	138	73	211	3	1	*4
	SHBV	161	76	237	8	3	11
	SYMBOL	123	78	201	2	1	*3
	LSD+30	151	75	226	3	3	*6
X2 Significance					not	not	.10
5/Day with Car	NONE	163	69	232	21	21	42
	LSD	162	90	252	23	20	43
	SHBV	126	75	201	29	14	43
	SYMBOL	124	63	187	19	16	35
	LSD+30	134	79	213	27	11	38
X2 Significance					.10	not	not
5/Night w/o Car	NONE	36	9	45	3	1	4
	LSD	52	6	58	0	0	0
	SYMBOL	37	18	55	4	0	4
X2 Significance					n/t	n/t	n/t
5/Night with Car	NONE	63	13	76	9	3	12
	LSD	58	6	64	9	2	11
	SYMBOL	59	13	72	5	3	8
X2 Significance					not	n/t	not

*: Indicates cells which are combined to form sufficiently large set of observations.

n/t: Not tested because of insufficient incidence of brake applications.

Table 29. Summary of Observational Study Behavior Data for Drift to Right Edge Line

Site/Condition	Treatment	Sample Size			Right Drifters		
		Not Opposed	Opposed	Total	Not Opposed	Opposed	Total
1/Day w/o Car	NONE	122	126	248	70	75	145
	LSD	124	135	259	59	74	133
	SHBV	129	133	262	65	78	143
	SYMBOL	140	147	287	76	100	176
	LSD+30	133	143	276	64	76	140
X2 Significance					not	not	not
2/Day w/o Car	NONE	197	124	321	16	24	40
	LSD	152	134	286	8	29	37
	SHBV	182	129	311	13	27	40
	SYMBOL	151	126	277	*1	18	19
	LSD+30	157	130	287	*4	29	33
X2 Significance					.01	not	not
5/Day w/o Car	NONE	133	61	194	*0	*1	*1
	LSD	138	73	211	*8	*6	*14
	SHBV	161	76	237	*4	*7	*11
	SYMBOL	123	78	201	*6	*5	*11
	LSD+30	151	75	226	*6	*13	*19
X2 Significance					.10	.01	.01
5/Day with Car	NONE	163	69	232	15	3	18
	LSD	162	90	252	5	6	11
	SHBV	126	75	201	12	14	26
	SYMBOL	124	63	187	5	6	11
	LSD+30	134	79	213	8	6	14
X2 Significance					.10	.05	.02
5/Night w/o Car	NONE	36	9	45	0	0	0
	LSD	52	6	58	3	1	4
	SYMBOL	37	18	55	1	1	2
X2 Significance					n/t	n/t	n/t
5/Night with Car	NONE	63	13	76	0	0	*0
	LSD	58	6	64	6	0	*6
	SYMBOL	59	13	72	5	8	13
X2 Significance					n/t	n/t	.01

*: Indicates cells which are combined to form sufficiently large set of observations.

n/t: Not tested because of insufficient incidence of Right Drift.

Table 30. Summary of Observational Study Behavior Data for Right Shoulder Encroachments

Site/Condition	Treatment	Sample Size: Not Opposed	Sample Size: Opposed	Sample Size: Total	Right Drifters: Not Opposed	Right Drifters: Opposed	Right Drifters: Total
1/Day w/o Car	NONE	122	126	248	1	4	5
	LSD	124	135	259	4	11	15
	SHBV	129	133	262	5	2	7
	SYMBOL	140	147	287	6	8	14
	LSD+30	133	143	276	5	9	14
x^2 Significance					· n/t	n/t	not
2/Day w/o Car	NONE	197	124	321	0	0	0
	LSD	152	134	286	0	0	0
	SHBV	182	129	311	0	0	0
	SYMBOL	151	126	277	0	0	0
	LSD+30	157	130	287	0	0	0
x^2 Significance					n/t	n/t	n/t
5/Day w/o Car	NONE	133	61	194	2	2	4
	LSD	138	73	211	0	0	0
	SHBV	161	76	237	0	0	0
	SYMBOL	123	78	201	0	0	0
	LSD+30	151	75	226	0	0	0
x^2 Significance					n/t	n/t	n/t
5/Day with Car	NONE	163	69	232	2	2	4
	LSD	162	90	252	0	0	0
	SHBV	126	75	201	0	0	0
	SYMBOL	124	63	187	0	0	0
	LSD+30	134	7[illegible]	213	0	0	0
x^2 Significance					n/t	n/t	n/t
5/Night w/o Car	NONE	36	9	45	0	0	0
	LSD	52	6	58	3	1	4
	SYMBOL	37	18	55	1	1	2
x^2 Significance					n/t	n/t	n/t
5/Night with Car	NONE	63	13	76	0	0	*0
	LSD	58	6	64	6	0	*6
	SYMBOL	59	13	72	5	8	13
x^2 Significance					n/t	n/t	n/t

n/t: Not tested because of insufficient incidence of Shoulder Encroachments.

Table 31. Summary of Observational Study Behavior Data for Drift to Left-Centerline

Site/Condition	Treatment	Sample Size: Not Opposed	Sample Size: Opposed	Sample Size: Total	Brake Application: Not Opposed	Brake Application: Opposed	Brake Application: Total
1/Day w/o Car	NONE	122	126	248	0	0	0
	LSD	124	135	259	2	2	4
	SHBV	129	133	262	1	3	4
	SYMBOL	140	147	287	2	3	5
	LSD+30	133	143	276	5	1	6
	x^2 Significance				n/t	n/t	n/t
2/Day w/o Car	NONE	197	124	321	10	15	25
	LSD	152	134	286	21	15	36
	SHBV	182	129	311	23	9	32
	SYMBOL	151	126	277	38	15	53
	LSD+30	157	130	287	8	2	10
	x^2 Significance				.01	.02	.01
5/Day w/o Car	NONE	[illegible]	61	194	9	*1	10
	LSD	138	73	211	27	11	38
	SHBV	161	76	[illegible]	21	*5	26
	SYMBOL	123	[illegible]	[illegible]	13	*4	17
	LSD+30	151	[illegible]	[illegible]	25	6	31
	x^2 Significance				.05	.02	.01
5/Day with Car	NONE	163	69	232	17	7	24
	LSD	162	90	252	32	10	42
	SHBV	126	75	201	14	10	24
	SYMBOL	124	63	187	23	9	32
	LSD+30	134	79	213	21	11	32
	x^2 Significance				not	not	not
5/Night w/o Car	NONE	36	9	45	0	0	*0
	LSD	52	6	58	5	1	*6
	SYMBOL	37	18	55	19	6	25
	x^2 Significance				n/t	n/t	.01
5/Night with Car	NONE	63	13	76	3	0	3
	LSD	58	6	64	17	1	18
	SYMBOL	59	13	72	18	1	19
	x^2 Significance						

*: Indicates cells which are combined to form sufficiently large set of observations.

n/t: Not tested because of insufficient incidence of left drifters.

Table 32. Intertrap Velocity Differences for Unopposed Vehicles

Site/Condition and Treatment	Mean Velocity Difference (ft/Sec) Trap 1-2	Trap 2-3	Trap 3-4	Trap 4-5
1/Day w/o Car				
NONE	-2.4	-3.5	-3.3	+2.9
LSD	-2.4	-3.7	-3.7	+2.2
LSD+30	-2.3	-3.4	-4.3	+3.4
SHBV	-2.1	-3.2	-4.1	+2.9
SYMBOL	-3.1	-3.3	-4.8	+2.5
2/Day w/o Car				
NONE	-8.4	+1.9	-0.5	-0.2
LSD	-8.9	+1.1	-0.5	-0.3
LSD+30	-10.3	+2.9	-0.6	-0.3
SHBV	-9.2	+1.5	-0.3	-0.6
SYMBOL	-8.9	+1.8	-0.5	-0.7
5/Day w/o Car				
NONE	+2.8	+1.1	-5.6	+0.4
LSD	+2.2	+0.6	-5.8	+0.5
LSD+30	+2.7	+0.8	-5.1	+0.3
SHBV	+2.3	+0.6	-5.5	+0.2
SYMBOL	+2.2	+0.6	-4.5	+0.2
5/Day with Car				
NONE	+2.6	+1.1	-5.9	-0.5
LSD	+2.5	+1.1	-5.0	-1.2
LSD+30	+2.0	+1.7	-5.5	-1.8
SHBV	+1.6	+0.6	-4.8	-1.5
SYMBOL	+2.1	+1.0	-5.3	-1.5
5/Night w/o Car				
NONE	+3.8	+0.8	-7.2	+2.0
LSD	+2.6	-0.1	-4.2	+1.1
SYMBOL	+2.3	+2.4	-4.5	+1.1
5/Night with Car				
NONE	+2.1	+1.0	-5.7	-0.6
LSD	+1.9	+0.3	-4.2	-1.1
SYMBOL	+1.7	+1.4	-5.5	-0.2

1 ft/sec = .30 m/sec

Table 33. Intertrap Velocity Differences for Opposed Vehicles

Site/Condition and Treatment	Mean Velocity Difference (ft/Sec) Trap 1-2	Trap 2-3	Trap 3-4	Trap 4-5
1/Day w/o Car				
NONE	-2.0	-2.9	-4.2	+2.9
LSD	-2.6	-4.3	-4.4	+3.3
LSD+30	-3.0	-4.1	-4.4	+4.0
SHBV	-2.9	-3.7	-4.7	+3.2
SYMBOL	-3.5	-3.0	-5.0	+3.1
2/Day w/o Car				
NONE	-8.6	+1.4	-1.2	-0.3
LSD	-8.7	+0.5	-0.9	-0.4
LSD+30	-9.4	+1.2	-0.9	-0.6
SHBV	-9.6	+2.0	-0.3	0.0
SYMBOL	-9.4	+2.2	-0.9	-0.6
5/Day w/o Car				
NONE	+2.4	+0.9	-5.4	+0.8
LSD	+1.4	+0.9	-6.3	0.0
LSD+30	+2.7	+1.0	-5.1	+0.6
SHBV	+2.1	+0.2	-5.8	+0.1
SYMBOL	+2.2	+0.7	-5.4	-0.2
5/Day with Car				
NONE	+2.7	+0.7	-6.3	-1.0
LSD	+3.2	+0.9	-5.3	-0.8
LSD+30	+2.3	+0.5	-5.7	-1.7
SHBV	+2.5	+0.7	-5.2	-1.2
SYMBOL	+2.1	+0.4	-5.3	-1.4
5/Night w/o Car				
NONE	+3.1	-0.1	-4.7	+2.3
LSD	+2.4	+1.0	-6.5	+2.5
SYMBOL	+2.1	+2.2	-3.9	+0.6
5/Night with Car				
NONE	+2.4	+0.2	-4.1	-0.7
LSD	+2.8	-0.6	-4.3	-1.8
SYMBOL	+2.7	+0.9	-4.5	-0.9

1 ft/sec = .30 m/sec

by drifting to the right (as far as but no farther than the right edge of the traveled way) varied among signs, but not consistently across sites. At site 1, no significant difference in frequency was found. At site 2, however, both the no-sign condition and the SHBV sign were associated with a greater than expected proportion of vehicles that moved toward the right edge line, while both the SYMBOL and the LSD+30 candidates had a lower than expected proportion. At site 5 during the daytime, the LSD and LSD+30 signs had more right-drifters when a parked vehicle was present.

Only at site 1 were vehicles found to drift so far to the right that they crossed onto the shoulder of the road. Because the shoulder of the road was substantially widened in the vicinity of the hill crest at this site, so much as to appear as if it were an additional lane, it was believed that this behavior was more a factor of this particular site than representative of behavior at vertical curves. Still, the LSD sign was found to be associated with a greater frequency of occurrence of this behavior than expected, while the SHBV candidate was associated with fewer vehicles crossing onto the shoulder than expected.

Finally, the proportions of vehicles that drifted left as far as the center line of the roadway were found to be significantly different among sign candidates at site 2 and site 5 only during daylight without the parked vehicle. At site 2, fewer vehicles than expected drifted left for both baseline and the LSD+30 sign, while a larger number drifted left for the SYMBOL candidate. At site 5, fewer vehicles than expected drifted left under the baseline condition, but more than expected drifted left for the LSD sign.

There were no consistent indications that any particular sign was associated with "safer" behavior than any other sign. If a judgment of safety is placed on each of the behavioral attributes such that "safer" is associated with braking and keeping to the right while "less safe" is associated with drifting to the left or crossing onto the right shoulder, each sign was associated with both safer and less safer behavior at every site.

6.5 Conclusions Regarding Field Experiments

It must be concluded that the nature of the effect that each sign candidate had on the behavior of drivers could not be measured using the techniques employed in the <u>observational</u> field study. It was <u>shown by the findings of the controlled</u> field study, discussed <u>in Chapter</u> 5, that driver behavior was measurably influenced by each of the candidate warning devices. That influence was measured in terms of a) the number of observations of certain driver responses, b) each driver's ability to freely recall, recognize, and comprehend each of the warning devices, and c) each driver's preference for each candidate limited sight distance device. It was evident that the existing LIMITED SIGHT DISTANCE and LIMITED SIGHT DISTANCE with a 30MPH advisory speed limit generally did not produce desirable driver responses as frequently, nor were they recalled, comprehended, recognized, or preferred as often as the SLOW HILL BLOCKS VIEW or the symbol signs. It can therefore be inferred that the SLOW HILL BLOCKS VIEW and symbol signs <u>do</u> result in modified driver behavior that we may speculate is associated with a greater driver awareness that a hazard may exist downstream, and also may result in a heightened level of alertness, compared to the existing LIMITED SIGHT DISTANCE signs.

Based primarily on the findings of the controlled field study, it is therefore concluded that the SLOW HILL BLOCKS VIEW verbal sign candidate and the symbol candidate are, at present, the most desirable choices to replace the LIMITED SIGHT DISTANCE sign. It is recommended, based on the finding that the symbol candidate resulted in the largest proportion of controlled study drivers who responded in an appropriate manner, that the symbol sign be used as the replacement for the LIMITED SIGHT DISTANCE sign. The symbol sign should initially be placed with a verbal supplementary panel stating SLOW HILL BLOCKS VIEW. Details of the guidelines for use and location of the replacement limited sight distance warning sign are presented in Chapter 7.

7. RECOMMENDED GUIDELINES AND CRITERIA

7.1 Warranting Conditions and Guidelines

The MUTCD (1) indicates that the existing LIMITED SIGHT DISTANCE sign, with supplemental Advisory Speed plate, is to be used on vertical curves where there is not sufficient stopping sight distance. Further, it is stated that the sign is not intended to serve as a substitute for an engineering solution to the stopping sight distance limitation at locations where engineering judgment has indicated that such a solution is warranted because of saftey considerations or other known problems.

That very broad-based criterion for the decision to either implement the limited sight distance warning sign (designated generically, henceforth meaning the recommended SYMBOL version) or to undertake an alternative engineering solution, leaves much room for interpretation by state and local agencies. For uniform application of the sign on a national basis, more specific quantitative criteria would be highly desirable. It was beyond the scope of this research project to develop criterion based on accidents. Similarly, the project scope did not provide for the development of criteria based on an examination of the effectiveness of the warning device at a wide variety of sites that encompassed the range of sight distance restrictions, hazard types, highway speeds, traffic volumes, and other independent variables that might be used to define a full experimental design. Therefore, the recommendations for warrants presented in this report must be somewhat more subjective.

In general, the limited sight distance warning sign should be used where the vertical alignment of a two-lane or three-lane highway causes the <u>stopping sight distance</u> to be less than the distance required for safe driving at the normal speed of traffic on that roadway in the vicinity of a <u>crest</u> vertical curve.

The length of a crest vertical curve required for stopping sight distance is calculated from the following expressions (source - ref. 2):

(1) $$L = \frac{AS^2}{100(\sqrt{2h_e} + \sqrt{2h_o})^2} \quad \text{for } S < L$$

(2) $$L = 2S - \frac{200(\sqrt{h_e} + \sqrt{h_o})^2}{A} \quad \text{for } S > L$$

Where

- L = length of vertical curve (ft)
- S = sight distance (ft)
- A = algebraic difference in grades (%)
- h_e = height of eye above roadway surface (ft)
- h_o = height of object above roadway surface (ft)

The value of h_1 has been accepted as 3.50 ft (1.07 m), and h_o is usually designated as 0.50 ft (0.15 m), thus equations (1) and (2) become:

(3) $$L = \frac{AS^2}{1329}$$

When S is less than L, or

(4) $$L = 2S - \frac{1329}{A}$$

When S is greater than L

The required lengths of vertical curves to provide adequate stopping distance for all values of A and for a range of design speeds may be calculated from:

(5) $L = KA$

The rounded values of K for a range of design speeds are listed in Table 34. The adequacy of the existing sight distance can be readily determined by comparing the required length of curve, calculated from equation (5), to the known length of vertical curve. Should the available sight distance be inadequate, the maximum safe speed for that curve may be determined by solving for K using the existing curve length and the existing gradient difference, then interpolating the design speed from the values in Table 34. That is the advisory speed limit that should be used in conjunction with the limited sight distance warning sign.

Table 34. K Values for Stopping Sight Distance on Crest Vertical Curve

Design Speed		K Value	
mph	kph	minimum	desirable
30	48	29	29
40	64	60	70
50	80	90	150
60	97	170	315
65	105	225	435
70	113	270	540
75	121	340	680
80	129	420	820

The Traffic and Safety Division of the New York Department of Transportation has prepared and incorporated into their state version of the MUTCD an expanded description of the purpose and application of the limited sight distance warning sign (7). Guidelines of that type are appropriate for national use, and are therefore presented with some editorial changes and additions, as follows:

GUIDELINES FOR LIMITED SIGHT DISTANCE SIGN

1. This sign may be used where stopping sight distance, as defined and used for highway design purposes, is limited by vertical highway alignment to a value that is less than adequate for the prevailing speed along the highway.

2. The sign should be used only at locations where engineering judgment indicates that warning of such limited stopping sight distance may be helpful in diminishing an existing or potential problem. The sign is primarily intended for use where resurfacing or minor road improvements are likely to increase speeds above the safe design value associated with the existing vertical alignment, or where such improvements or other local highway conditions have resulted in a level of driver attentiveness below the level that is deemed appropriate for safe vehicle operation in the area of the existing vertical alignment.

3. The sign should be supplemented with the appropriate Advisory Speed plate which indicates the speed for which the limited stopping sight distance is deemed adequate, if that speed is different than the regulatory speed limit posted on the highway in the nearby vicinity of the vertical curve.

4. Where this sign is used on a two- or three-lane two-way highway (which has pavement markings), a no passing zone in the appropriate direction of travel shall be marked through the entire section where stopping sight distance is deemed inadequate. Where the resulting no-passing zone would be less than 400 ft (122 m), it shall be extended to 400 ft (122 m) by adding the additional length at the beginning of the zone. Where an existing no-passing zone marking includes part, but not all, of a limited sight distance section, such zone shall be extended as necessary to include the entire section.

5. The reference point for the advanced posting of this sign is the beginning of the highway section in which stopping sight distance is deemed inadequate. The sign should be placed about 750 ft (229 m) in advance of the reference point. This placement location may be adjusted to reflect existing traffic speed and local geometric conditions, such as the presence of intersections, driveways, other signs, and obstructions.

6. It is adviced that a supplementary panel, 18 in (46 cm) by 24 in (61 cm) bearing the legend SLOW HILL BLOCKS VIEW be used with the symbol sign for the limited sight distance warning for a period of time sufficient for motorists to become accustomed to the meaning of the symbol sign.

7. A supplementary sign panel may be used to indicate the specific nature of the hazard if it is belived that the provision of such information will aid in increased driver attentiveness and/or a speed adjustment. Supplementary panel legends may include INTERSECTION, DRIVEWAY, or very brief identification of other permanent potential hazards.

It should be noted that when planning the installation of the sign, the number of possible supplementary panels must be kept to a reasonable number to avoid motorist confusion and an overload of information. For example, the earliest installations of the sign could include the primary symbol sign diamond-shaped panel, a rectangular SLOW HILL BLOCKS VIEW legend, a rectangular hazard advisory panel such as INTERSECTION, and a rectangular advisory speed limit panel. In such a case, it may be advicable to either combine the hazard advisory with the sign legend, which would be removed after several years and replaced with the hazard advisory alone, or to use a separate sign installation to warn of the specific hazard, using the symbol sign for a Cross Road (W2-1), Side Road (W2-2, W2-3), T symbol sign (W2-4), or Y symbol sign (W2-5), or other appropriate warning device.

The technical specifications for the SLOW HILL BLOCKS VIEW symbol sign and supplementary panels are presented in the APPENDIX.

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APPENDIX - TECHNICAL SPECIFICATIONS

This appendix contains the technical specifications for the SLOW HILL BLOCKS VIEW sign and the supplementary verbal panel which should be used with the symbol sign until drivers become accustomed to its meaning.

The following table provides key dimensions for warning signs and panels in 30 in x 30 in (76 cm x 76 cm), 36 in x 36 in (91 cm x 91 cm), and 48 in x 48 in (122 cm x 122 cm) sizes.

Symbol Sign Specifications

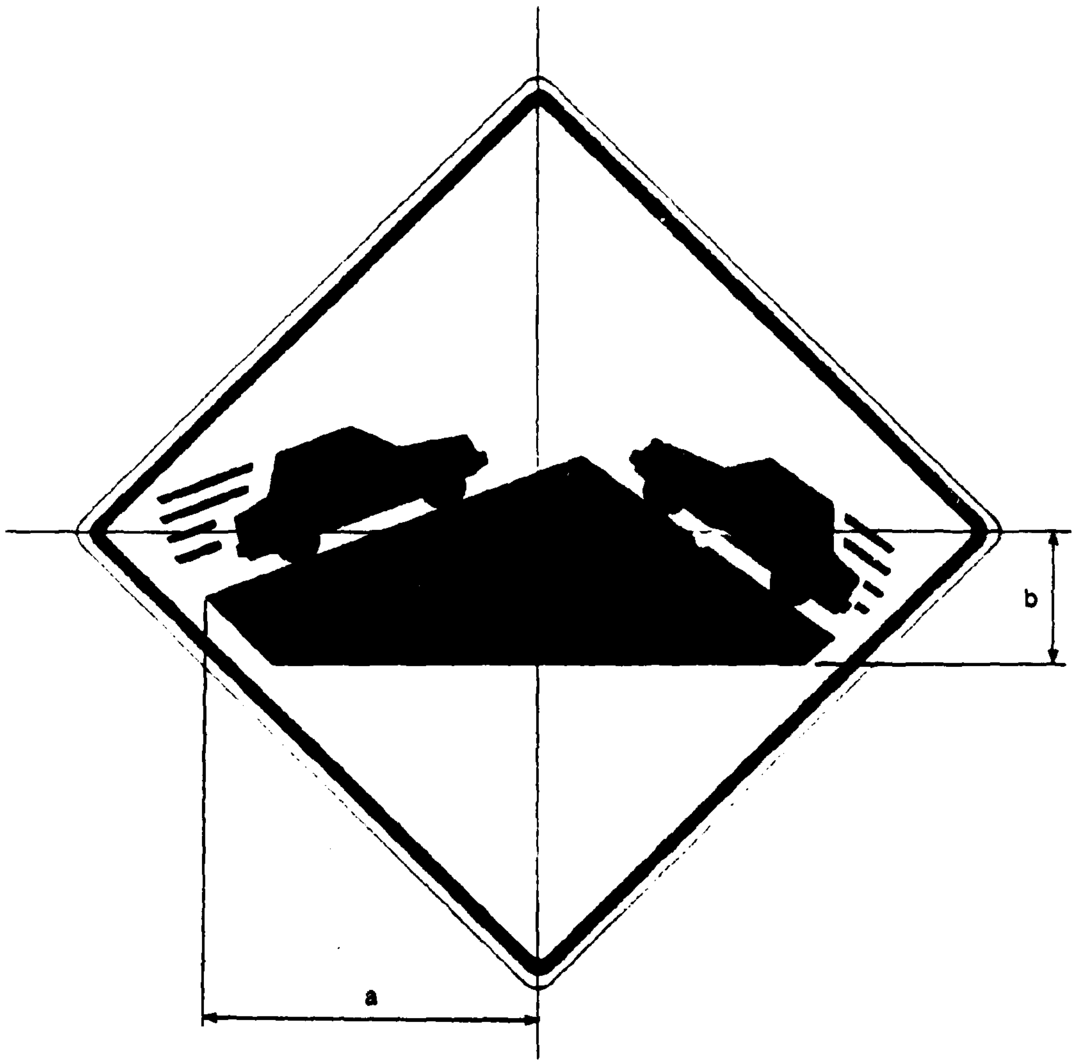
Size	Margin	Border	a	b	Supplementary Panel Size
30"x30"	1/2"	3/4"	15"	6"	18" W x 24" D
36"x36"	5/8"	7/8"	18"	7 1/4"	24" W x 30" D
48"x48"	3/4"	1 1/4"	24"	9 5/8"	30" W x 40" D

note: 1" = 2.54cm

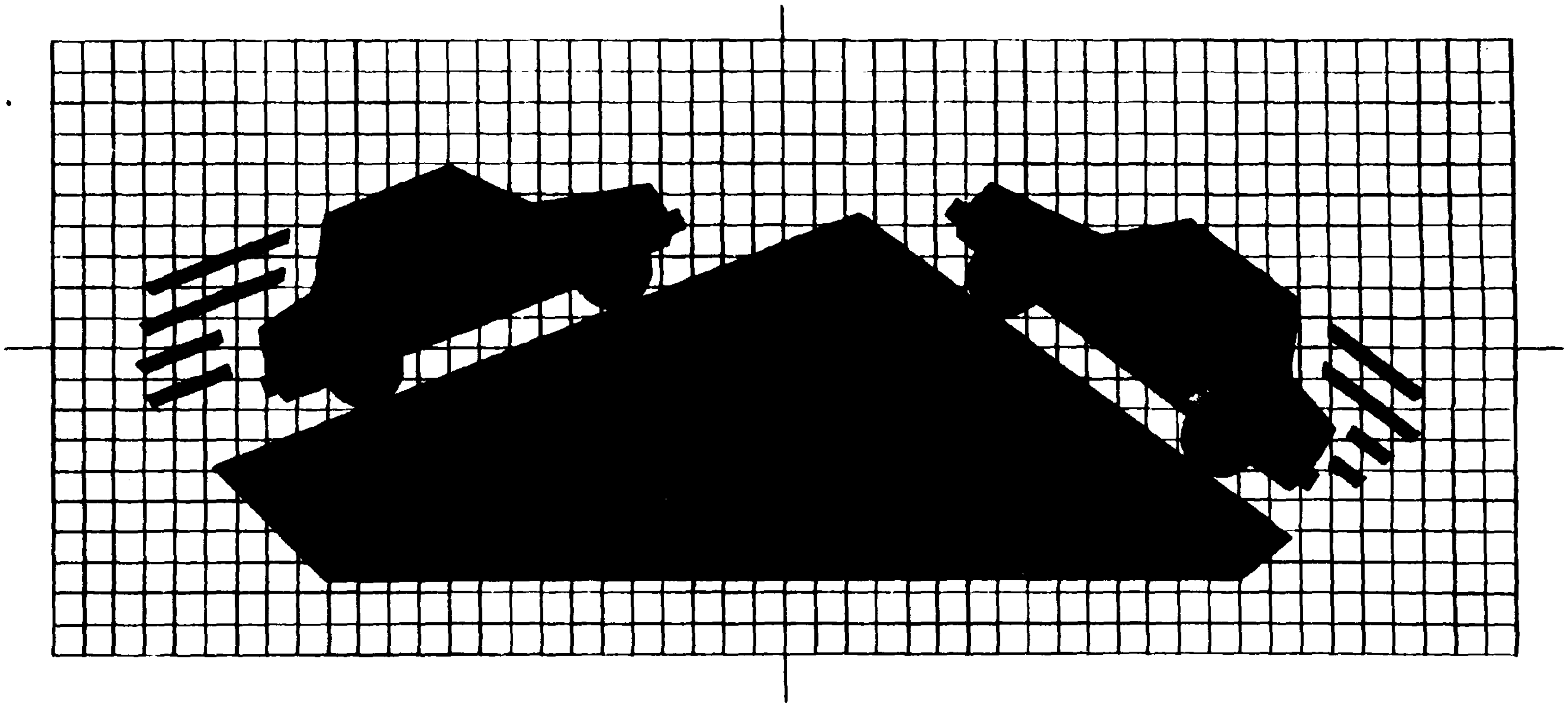
Supplementary Panel Specifications

Size	Margin	Border	Letter Size (all Series C or D)			
			SLOW	HILL	BLOCKS	VIEW
18"x24"	3/8"	1/2"	4"	3"	3"	3"
24"x30"	1/2"	3/4"	5"	4"	4"	4"
30"x40"	3/4"	1"	6"	5"	5"	5"

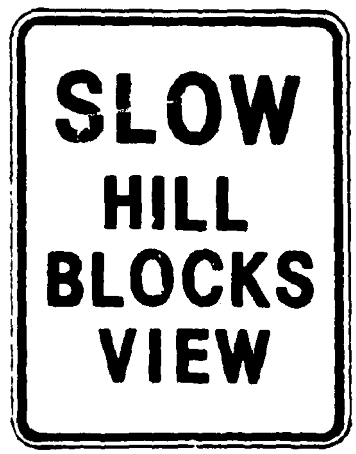
note: 1" = 2.54cm



Recommended Symbol Sign



Template for Recommended Symbol



Recommended Supplementary Panel