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DRIVER AWARENESS OF HIGHWAY SITES WITH HIGH SKID ACCIDENT POTENTIAL

F. R. Hanscom

July 1974
Final Report

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16. Abstract

This field study examined driver responses to two types of potential highway skidding hazard: wet pavements subjected to high frictional driving demands, and bridges during periods of possible preferential icing. Study objectives were to examine motorists' general awareness of the hazards and to assess the relative effectiveness of various signing treatments which warn of the hazards. Measures of signing effectiveness were motorists' speeds at critical driving locations and questionnaire responses regarding motorists' observations and interpretations of the signs.

Three curved highway sections were treated with five experimental signing conditions. Variations on the "Slippery When Wet" symbolic sign ranged from its use by itself, through increasing levels of specificity and conspicuity, to its use with flashing lights and an advisory speed limit. Experimental signing conditions incorporating flashing lights were effective at reducing highest quartile mean speeds below the critical safe wet pavement speed based on roadway geometry and surface conditions. Questionnaire results indicated that 60 percent of the interviewed motorists saw and properly interpreted the more conspicuous warning signs. Motorists' cues of potential hazard were observed to be: roadway curvature and superelevation, behavior of other motorists, appearance of pavement surface, ambient conditions, known site accident history, and presence of the warning sign. About one percent of the interviewed motorists cited the warning sign as their cue of potential skidding hazard.

Two bridge approaches were signed using combinations of activated and nonactivated signs both at the bridge and in advance of the bridge during periods of possible preferential icing. Significant speed reductions on the bridge and at the bridge entry point were elicited by activated signing. Activated signing used at the bridge was observed to have a greater impact than activated signing used at the advance location. Drivers were more responsive to the signs during periods when the hazard was greater.

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ABSTRACT

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Two bridge approaches were signed using combinations of activated and nonactivated signs both at the bridge and 1,000 feet in advance of the bridge during periods of possible preferential icing. Significant speed reductions on the bridge and at the bridge entry point were elicited by activated signing. The most effective sign condition was advance and bridge located activated signing used during hours of darkness. Activated signing used at the bridge was observed to have a greater impact than activated signing used at the advance location. Drivers were more responsive to the signs during periods when the hazard was greater. Bridge approach roadway geometry was seen to impact on motorists' observation and speed reduction in response to the signing. Improved results were obtained on the short sight-distance approach where the bridge did not visually compete for driver attention.

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INTRODUCTION

The need to develop innovative countermeasures aimed at the reduction of skidding accidents is long overdue. Two decades of study within the highway research community have been restricted almost exclusively to the tire-pavement interaction phenomenon. A few remedial products developed by the automotive industry have been limited to anti-skid braking systems. But by the time such a device is needed, it is already too late for prevention! No concerted effort to examine broadly based causes of skidding accidents has ever been documented. Most sorely neglected is the cause of all skidding accidents – the driver.

The importance of the human element in skid accident prevention was documented at the First International Skid Prevention Conference held at Charlottesville, Virginia in 1958. At that time, the importance of gaining knowledge of skid hazard-related driver information needs and of providing warning to motorists of potential hazards was realized.

Investigation of the relationship between the driver and those environmental factors which affect the operation of his vehicle is an ultimate means for deriving insight into the cause of any accident. Previous work dealing with tire-pavement interactions has provided definitive knowledge regarding the extravehicular conditions (roadway geometry and weather) which are known to comprise skid hazards. However, skidding accidents occur because the motorist is generally unaware of the existing threat. The research undertaken here is based on the need to induce motorists' awareness of hazard and to examine remedial measures to elicit their safe response.

The objective of this study was the exploration of signing as a more cost-effective technique to reduce skidding hazard than the traditional approach of providing highly skid-resistive pavement surfaces. The target situation was the roadway section which is subjected to high frictional pavement demand, particularly when the pavement is wet. We expanded the project scope to include the examination of signing effectiveness to warn of potentially icy bridges.

Consideration of general warning sign feasibility gave rise to a number of diverse issues. Although the perceived credibility by the motorist of any warning device is the paramount issue, the political feasibility of the device to the implementing highway agency is a matter of essential concern. Therefore, the timely issue of liability implications of hazard warning was treated. The impetus for this consideration arose from the refusal of one state highway agency to permit any sign displaying the word 'Slippery" to be used, even on a short-term experimental basis.

The thrust of the effort was a field examination of driver responses to varying degrees of potential skid hazard and the influence of varying levels of warning signing. That the driver was actually apprised of the hazard through sign display was addressed by interviewing him. The assessment of driver sensitivity to the hazard cues and its relationship to certain driver characteristics was examined.

This report is structured into five sections. First, a lengthy review of pertinent literature covers work related to the causal factors and measurement techniques associated with pavement skid-resistance, the driver in a potential skidding environment, related traffic signing studies, and special consideration of the icy bridge hazard in terms of both its causal factors and documented attempts to evaluate icy bridge warning signs. Then follows a section dealing with liability for the skid hazard and its interface with warning signs. The reader who is merely interested in the subject experimentation described by this report may omit these first two sections and proceed to page 48 for the section dealing with study procedure. The following section describes the analysis and results obtained for vehicle speed studies at wet pavement and icy bridge sites. That section concludes with a discussion of questionnaire results obtained for each hazard type. Finally, study conclusions relate to observed effectiveness of signing and future research needs.

LITERATURE REVIEW

A comprehensive review of all documented research relevant to skidding accident hazards would be impractical. Many hundreds of references can be cited in the area of skid resistance measurement alone.

The intent of the review is to provide background relevant to selected research in certain areas pertinent to the objectives of the study. As this project is primarily concerned with the skid-accident hazard, the motorist's recognition of that hazard, and the evaluation of some remedial signing measures, the background literature is somewhat restricted. The review first presents a discussion of work which relates to the skid hazard in terms of its causal factors. The review is then confined to a brief overview of skid-resistance measurement procedures, an explanation of literature related to the driver in a skid-risk environment, a summary of research effectiveness of selected traffic control principles, and a section on the icy bridge hazard.

Skid Resistance – Factors and Measurement

The literature published on skid resistance is bountiful. Document searches preparatory to this review uncovered bibliographies containing 500 references to skid resistance studies which dealt with the development and correlation of skid measurement techniques, the determination of pavement skid resistance requirements, and the interaction between tires and road surfaces. To summarize all of the literature on skid resistance would obviously be an awesome task and would be of only marginal benefit to this study. Fortunately, there exists a recent synthesis (NCHRP, 1972) on skid resistance which deals with its measurement, operational requirements, control, and relevant pavement characteristics.

The extent to which skid resistance measurement is covered in this review is limited to a brief overview of measurement techniques and an explanation of the technique selected for use in this research. Factors which affect skid resistance are presented first in the review by way of introduction to the skid resistance phenomenon, problems related to it and considerations of its measurement.

Factors Affecting Skid Resistance

Road, vehicle, and environmental factors all contribute to skid resistance. Road factors involve surface type, aggregate characteristics, surface texture, geometric design, and polishing. Vehicle factors are speed, braking frequency, vehicle trajectory, and tire characteristics.

Environmental considerations are wetness, temperature, water film depth, and air pressure. The relative extent to which each of the factors contributes to skidding accidents is not known, but an explanation of the more significant factors follows.

Initial Surface Texture. Research presented at the First International Skid Prevention Conference (Moyer, 1959) showed skid resistance to be related to original surface treatment (concrete or bituminous), aggregate type, and amount of binder used. Tests conducted on bituminous pavements have indicated that rock asphalt surfaces have better skid resistance properties at speeds up to 50 mph than any other surface type (Michael, 1959); and that, on the average, test results are almost as good on hot mix and seal coat asphalt-type surfaces. Variations such as the addition of small amounts of powder rubber (Shelburne & Sheppe, 1950) have given bituminous pavements good initial skid resistance.

Much work has been done in the area of improving the initial skid resistance of Portland cement concrete pavement by use of brush treatments during construction (Moyer, 1959, and others); but the effects of pavement wear due to traffic have been known to reduce the effect of initial pavement roughness.

Pavement Wear. Any kind of pavement wear causes changes in time which alter the initial skid resistance characteristics. Wear results in the removal of outer layers of pavement and is largely a function of aggregate composition. It is not fully understood in terms of all its ramifications and complications that exist on a highway surface. Research on wear rates as related to aggregate material hardness and mineral content (Stiffler, 1969) indicates that road stones wear by scratching and pitting. Rapidly wearing materials exhibited evidences of both types of attrition, whereas slower wearing ones showed mostly scratching. The work established that the hardness of the mineral relative to that of the abrasive is decisive for the rapidity of wear. If the abrasive is harder than the mineral, wear is fast. Stiffler found no adequate general model for relating the rate of wear to known properties of the minerals, but he did develop some qualitative relations.

However, aggregate wear is not identical with pavement wear. This is especially true for Portland cement concrete. The relative hardness of mortar and aggregate can make the wear rate drastically different from what it would be for either mortar or aggregate alone.

As was mentioned above, brush treatments improve the initial skid resistance quality of Portland cement concrete by increasing surface roughness. This roughness is largely affected by wearing due to volume of traffic. Damage to the initial surface texture can be seen in the reduction of the side friction factor due to average daily traffic volume. This is illustrated in Figure 1, and based on observations in Britain (Road Research Lab, 1971).

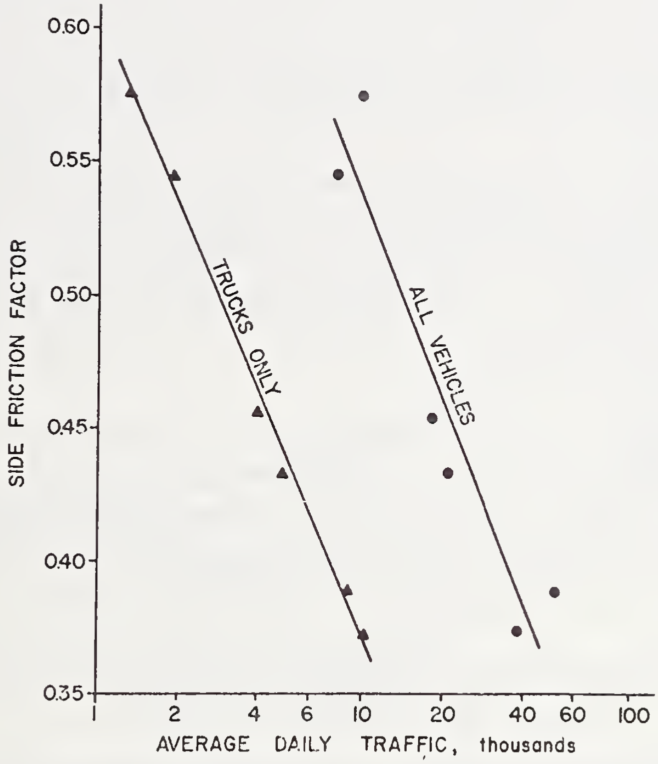


Figure 1. Reduced skid resistance as a function of traffic volume.
(NCHRP, 1972)

Polishing. The reduction of microtexture referred to as "polishing" is very similar in its effect to the reduction in macrotexture described as "wearing." The terms are often used interchangeably. The primary difference is that polishing is determined by the coarse aggregate wearing characteristics. This distinction is made for the case of bituminous concrete. Much research has been done by the Road Research Lab (Maclean & Shergold, 1958) to examine the mechanism of polishing and its effects on skid resistance.

Wetness. The effect of water on a range of tire-pavement friction availability as a function of speed can be seen in Figure 2 (Kummer & Myer, 1967). Water accumulation on the pavement has a dual effect on the tires. Inertia forces are exerted on the tire as water in its path is displaced, and remaining water between the pavement and tire acts as a lubricant. The effect of wetness is complicated by numerous variables such as pavement texture, water temperature (viscosity), water film thickness, tire tread and pressure, and vehicle speed. The best example of the interactive effects of these variables is the hydrodynamic uplift phenomenon known as hydroplaning.

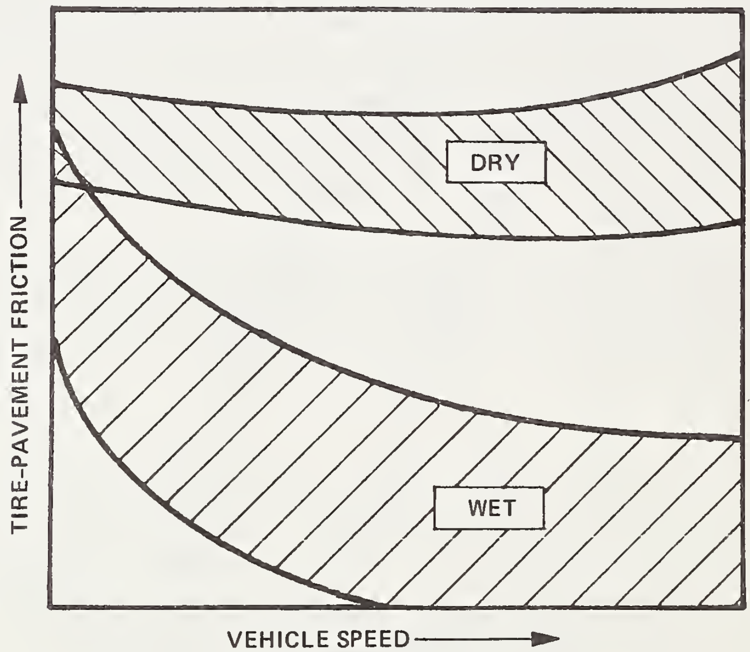


Figure 2. The effect of water on tire-pavement friction as a function of speed. (Kummer & Myer, 1967)

High Vehicle Speeds. As vehicle speeds increase, the time available to remove water from the tire-road surface becomes less. Therefore, the water film which remains between the tire and road increases, and the available stopping friction is reduced. This condition is the cause of hydroplaning at high speeds when combined with sufficient tire pressure and water film thickness. Some research on the effect of speed has resulted in a theory which proposes that the decrease in skid resistance is caused by the development of steam resulting from a transformation of energy (Obertop, 1962). The kinetic energy of the moving vehicle is irreversibly converted into other types of energy, including heat created at the tire-pavement contact area. This heat raises the temperature of the water at this contact area to a point where the pressure exerted by the tire creates steam. When this occurs, adhesion becomes zero at the point of contact. As the speed of the vehicle increases, the amount of steam generated increases, and the average coefficient drops. Obertop further suggested a mathematical equation to define the coefficient at any speed after calculating the coefficient at any two speeds.

Total hydroplaning, or the separation of the tire and pavement by an intervening water film, results in almost complete loss of braking traction and cornering capability. Before total hydroplaning can occur, the depth of water on the pavement must exceed the tread depth of the tire plus the amount necessary to submerge the asperities of the pavement. The latter condition depends on the texture of the pavement surface.

Use of Studded Tires. A study of skid resistance on badly stud-eroded pavements has shown that studded tires do cause excessive pavement wear (Preus, 1971). Other studies have rendered similar conclusions, while it has also been shown that studded tires produce little or no tractive advantage in loose snow or sanded and cindered surfaces (Rosenthal et al., 1969).

The need for winter usage of studded tires over most of the nation is limited due to the "bare-pavement" snow and ice removal policy of most highway departments. The results of numerous documented stopping distance tests have shown that studded tires exhibit reduced frictional capabilities on wet and dry pavement. Work is now underway to correlate the observed number of vehicles with studded tires to measure pavement friction in the area.

The six factors listed above do not represent the complete array of influences on skid resistance. The literature contains much information on the effects of air resistance, vehicle dynamics, tire inflation pressure, traffic density, bleeding of asphaltic pavements, compaction, rutting, contamination of air pollutants, uneven pavement surfaces, and runoff changes (NCHRP, 1971; Csathy, 1964; Rizenbergs & Ward, 1967).

To summarize the effect of primary contributing factors to the problem of skid resistance, Figure 3, from Kummer and Myer (1967), illustrates an interaction of the principal causes of skidding which are pavement wetness, high vehicle speeds, and high traffic density.

Measurement of Skid Resistance

Voluminous literature is available relevant to the measurement of skid resistance; however, the discussion here is limited to selected concepts and methods in order to present an overview and to provide rationale on the measures used in this study.

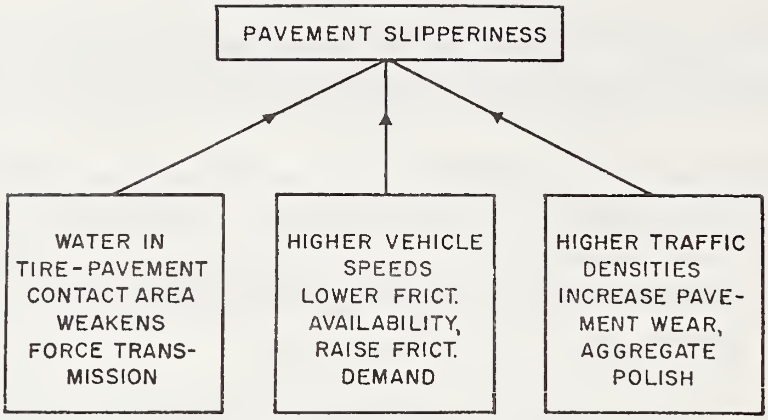


Figure 3. Principal causes of pavement slipperiness.
(Kummer & Myer, 1967)

Around the end of the last century, the criterion measure employed for arriving at a value for road slipperiness was the distance traveled before a horse fell. Empirical consideration was even given to the seriousness of the fall; e.g., falls upon the knees, falls upon the haunches, and complete falls (Goodwin & Whitehurst, 1959). Since those days, methods have changed drastically. The number of techniques employed has increased, resulting in greater levels of sophistication; but the interpretation of results has become significantly more complicated.

Numerous skid resistance tests have been performed using a wide variety of techniques. The instruments which are used cause variations in results obtained because of the differences in their inherent features. Consequently, the resulting measurements do not reflect actual pavement friction characteristics, but rather can be considered as performance values taking into account such things as tire properties, device constraints, operating conditions, and environmental factors.

The mode of operation gives rise to a natural classification of skid resistance measuring devices and methods (Csathy, 1964). A listing and brief explanation based on this classification follows.

- *Sideway Force Method.* The side thrust component of frictional force is determined by a rolling wheel set at an angle to the direction of travel.
- *Braking Force Trailers.* The frictional force component in the plane of the wheel as brakes are applied is divided by the vertical force on the tire and the ratio is expressed as a Braking Force Coefficient.
- *Stopping Distance Method.* A Measure is made of a four-locked-wheel stopping distance, and the test is generally performed using a standard passenger car.

- *Portable and Laboratory Instruments.* The most widely used are: (a) the British Portable Tester which derives frictional resistance from loss of potential energy in a swinging arm on which is placed a rubber slider that comes in contact with the pavement; (b) the Leroux Rugosimeter, a French application of the swinging pendulum; (c) the California-type Skid Resistance Tester, a free-spinning tire of a desired rpm, mounted on a carriage which moves when the assembly is dropped on the test surface; (d) a Russian hand-operated device using a dynamometer to measure frictional resistance; and (e) the Keystone Mark IV, a device with a rubber shoe which is dragged on the test surface and converts frictional resistance to hydraulic pressure displayed on a gauge.

Table 1, from Kummer and Myer (1967), compares various types of testers on the basis of their suitability for routine surveys.

The above skid resistance measurement techniques take a "direct" reading of pavement friction. A fifth technique, the decelerometer method, is based on a reading of longitudinal g-force measured in a vehicle as the wheels are locked and the vehicle begins to skid. The method has been widely researched and practiced (Dillard, 1962; Dillard & Allen, 1959; Giles & Lander undated; Giles, 1957; Giles & Sabey, 1958; Grime & Giles, 1954-55; Moyer & Shupe, 1951; Wilkes, 1956; Wilkes, 1960; Florida, 1959; Nichols, Dillard & Alwood, 1956; Shupe, 1960; Fabian, 1959; Machine Design, 1945; Starks & Lister, 1951; Allen & Dillard, 1960; Road Research Board, 1962; Jatrzebski, 1961; Marshall & Gartner, 1962; Van Breeman, unpublished; Maner, 1959; Goetz & Rice, 1959; Rankin, 1971; and Shrager, 1962).

The decelerometer method was selected for use in this study in an attempt to determine hour-to-hour wet pavement skid resistance variation. The compatibility of the measure to the objectives of the study as they relate to driver awareness of skid hazard was one of the most important reasons for its selection. The locked-wheel deceleration of a vehicle as it varies with existing pavement friction is a measure which is directly perceptible to a motorist. Pavement friction measured by any other of the above mentioned techniques does represent a significant physical property relating to vehicular behavior under given conditions. However, the only direct stimulus available to a motorist is the manner in which his vehicle decelerates or slips as a result of that physical property.

Table 1
Summary of Pavement Friction Tester Suitability

Criterion	Portable Testers	Stopping Distance Cars	Skid Trailers
Meaningful measurement	Poor to good	Good	Good to excellent
Accuracy of test data	Good	Poor to good	Good to excellent
Data display	Indication	Indirectly derived	Recording
Test frequency	Poor	Poor	Good to excellent
Operating range	Poor	Poor to good	Good to excellent
Mobility and maneuverability	Good to excellent	Excellent	Poor to excellent
Traffic interference	Very high	High	Low
Ruggedness	Good	Poor	Good to excellent
Hazard to test crew	High	Very high	Low
Required test crew, minimum	1 – 2	3 – 4	1 – 2
Procurement and operating cost:			
Initial cost, average ($)	900	3,500	10,000 – 25,000
Sites tested per day (no.)	8 – 12	15 – 25	100 – 400
Life expectancy (yr.)	6	2	5
Maint. and direct cost per season ($)	50	1,250	1,250
Total wages per season ($)	4,200	8,400	4,200
Cost per site tested ($)	3.45	4.70	0.32

Kummer & Myer, 1967.

Other reasons for selection of the measure have to do with the practical aspects of collecting the data. No large trailer is needed which may impede traffic and would be noticeable to motorists passing through the test site. Further, measurements of skid resistance at the precise location of the pavement which would affect motorists can be made rather unobtrusively.

Although no identical application (motorist awareness) of the method was noted in the literature, substantial usage was documented to justify the method. Braking force is obtained from the simultaneous locking of all four wheels of a test vehicle (standard passenger car) by recording the retardation force or deceleration. The coefficient of friction is numerically proportional to the deceleration expressed in g's (Dillard, 1962; Giles & Lander, undated; Giles, 1958; Giles & Sabey, 1958; Grime & Giles, 1954-55; Moyer & Shupe, 1951; Wilkes, 1960).

The skid resistance measurement technique used to characterize two sites in this study was the standard ASTM E274-70 test conducted by the Maryland State Highway Administration. This locked wheel test utilizes a measurement representing the steady state friction force of the wheel dragged over a uniformly wetted pavement. The procedure is the most reliable available, and the only disadvantage was that skid resistance measurement and other data could not be gathered concurrently.

The Driver and Skid Potential

Among the hundreds of items searched on skidding, not one related directly to driver assessment of skid hazard. One unpublished item (Bergt & Hart, 1971) attempted a study of steering and the detection of skidding by the motorist, but the project was dropped after five years of effort. As this study was originated in The Netherlands, it was not possible to contact the researchers. Therefore, items of literature which relate to elements in the driving environment that contribute to skidding accidents are reviewed as a basis for inferences relative to the impact of those elements upon motorist reaction to a potential skid hazard.

In a report presented during the First International Skid Prevention Conference (Accidents and the Human Element Subcommittee, 1958), the driver was recognized as a dominant factor in skidding accidents. An analysis of the driver-vehicle-highway relationship in skidding accidents prompted a listing of matters which are misunderstood by the driver. The directly quoted list is as follows:

1. Friction between tires and road is often greatly reduced when the road surface is wet, increasing vehicle stopping distances vary greatly. The effect of wetness on slipperiness varies greatly with different road surfaces, however.
2. Such friction for an emergency stop on most wet road surfaces is much lower in high speed stops. In a quite high-speed stop on a wet road, such friction is almost as low as that on ice.
3. Some road surfaces which are very non-skiddy when dry become treacherously slippery when wet.
4. When a road surface is wet, its slipperiness cannot be judged at all by a motorist looking at it.
5. A shower after a dry spell on a heavily traveled highway may cause the highway, due to oil drippings and road film, to suddenly become very slippery until the rain cleans off the surface—even on the best of road surfaces.

6. Even the slightest swerve, brake application, or speed-up can "trigger" a skid on wet or icy road surfaces. The higher the speed, the more true this is.
7. Unevenly or badly worn tires may result in skidding and loss of control on wet roads, the conditions of which are otherwise excellent.
8. Skidding is especially likely to occur at curves, near intersections, on steep hills, at traffic circles. One reason is greater pavement wear resulting in lowered friction coefficients. These are also places where drivers decelerate sharply, swerve, or otherwise change course rapidly.
9. Many drivers have not developed patterns for action in skids—and understanding of what not to do. These are things which cannot be learned by reading alone—they must be experienced.

Following the generation of that list, the subcommittee made a series of recommendations for remedial measures, one of which was that research agencies should study what motorists know about skidding. However, no such research was cited during the conduct of this literature search.

The role of the driver is included in an analytical systems approach aimed at identifying the interdependence of factors influencing the skidding accident (Hankins et al., 1971). The resulting model is rather complex as can be seen in Figure 4. It is asserted by the authors that the driver's portion of the model is the most difficult to evaluate because of problems in determining the driver's psychological and physiological conditions. A primary factor affecting the driver is his experience, in addition to his psychological and physiological makeup. Components of all three factors are shown in Figure 5; it is the sum total of these interactions which affects the driver's perception of his overt actions which lead to accidents.

The importance of the physical environment as it communicates to the driver can be seen from the model. Figure 6 illustrates the formal and informal sources of communications received by the driver. Formal channels are traffic control devices (signs, signals, markings) specifically intended for the purpose of communication to the motorist. Informal communication is derived from geometrics, guardrails, delineators and roadway alignment. The combination of these elements influences the motorist and elicits a maneuvering response.

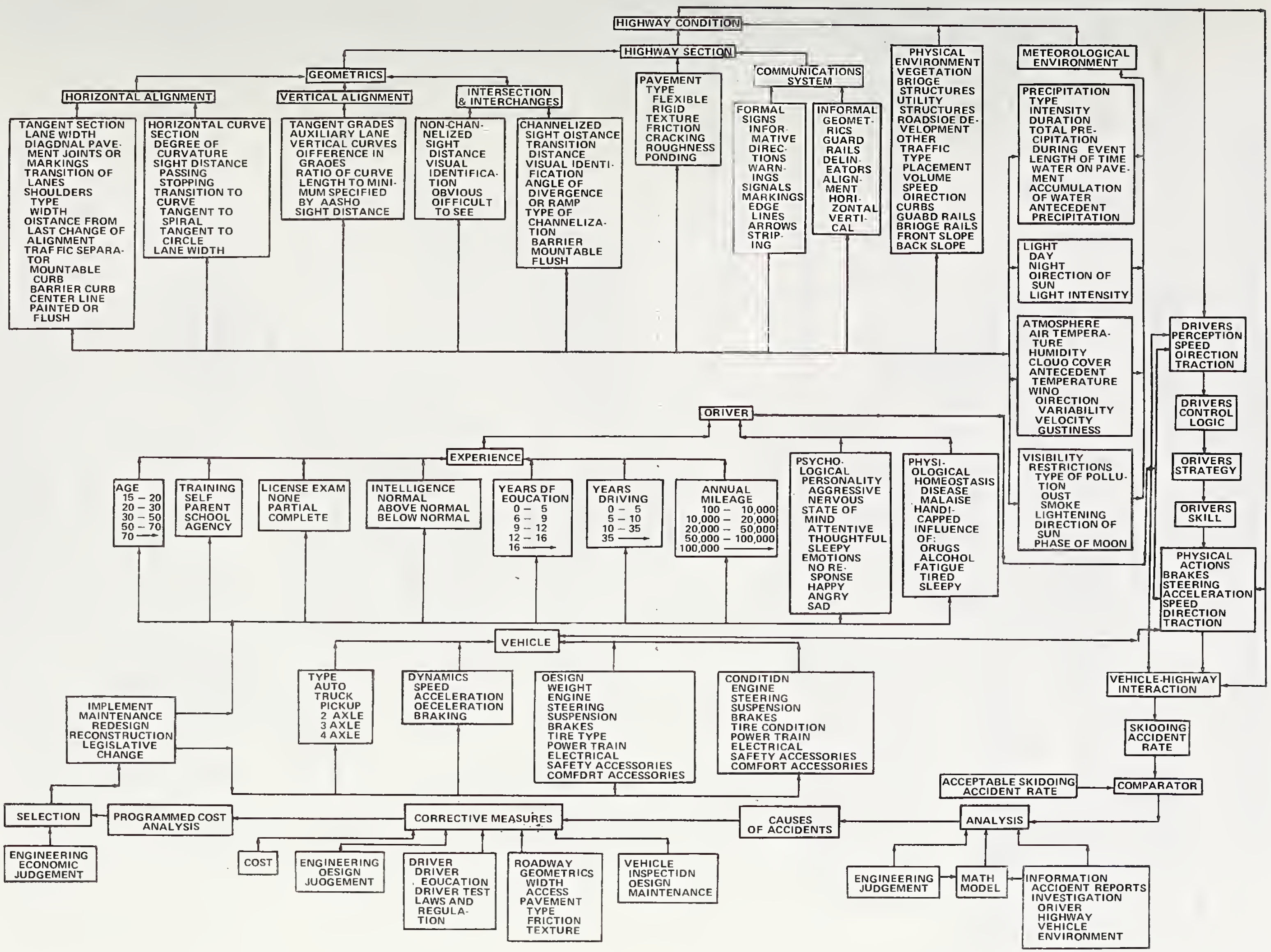


Figure 4. Skidding accident systems model. (Hankins, 1971)

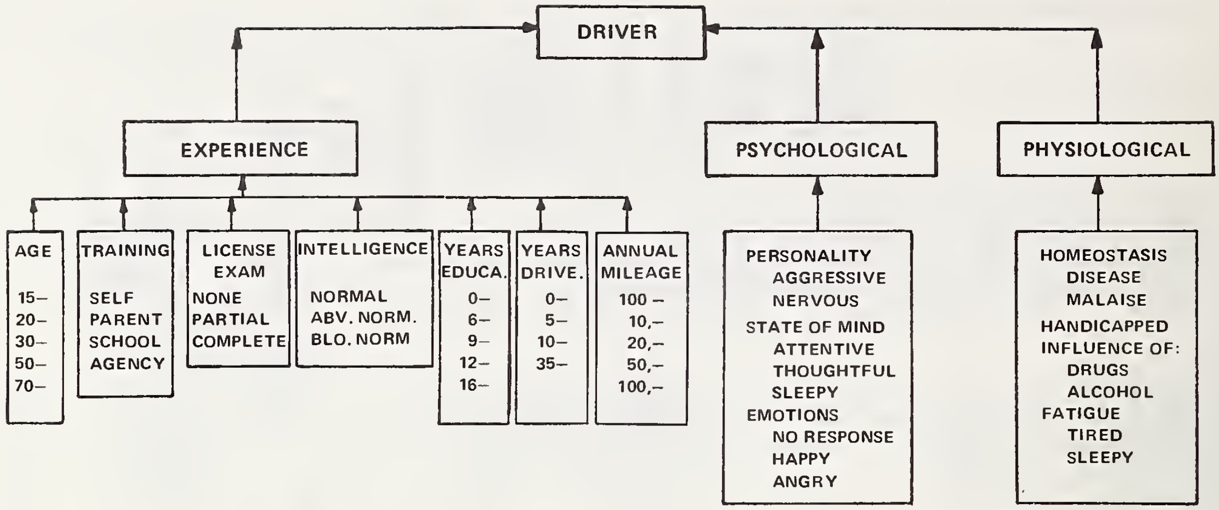


Figure 5. Driver components in the skidding accident systems model. (Hankins, 1971)

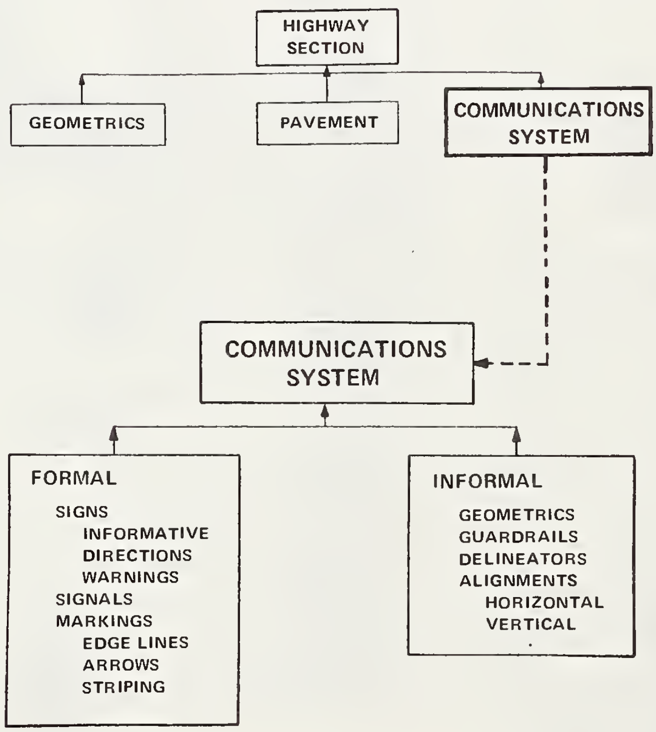


Figure 6. Communications system components of the skidding accident systems model. (Hankins, 1971)

A study of driver sensory capability at the Ohio State University (Rockwell et al., 1968) has led to a driver's longitudinal control task model derived from the elementary stimulus – response concept of classical psychology. Figure 7 depicts the model in which the human controller is seen to receive vehicle dynamic stimuli and to determine the appropriate response as a function of both his perceptual characteristics and operating criteria. The combination of models derived by Hankins and Rockwell seem to closely represent a conceptual description of the driver in a potentially skid hazardous environment.

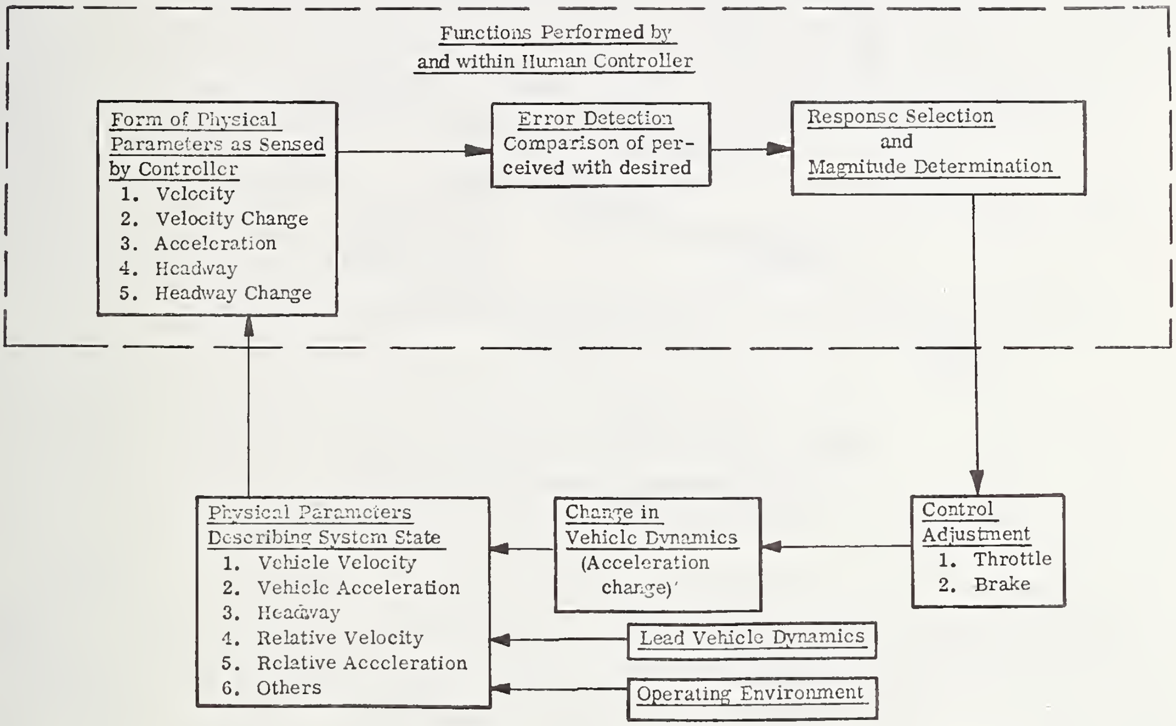


Figure 7. Hypothesized function of driver in longitudinal control task.
(Rockwell & Snyder, 1968)

In a recent study of vehicle and roadway interaction, the requirements placed on the motorist in a potential skid hazard can be seen in terms of the maneuvers which create a frictional demand (Ivey et al., 1971). Applicable driving maneuvers are classified as acceleration, deceleration, and cornering. Consideration is also given to two combinations of these—acceleration and deceleration while cornering—which comprise two of the driver maneuvers studied in this report. Deceleration demand has been defined as the "numerical" equivalent to pavement frictional requirements. The importance of vehicular deceleration capabilities as they relate to pavement skid resistance is cited in numerous studies (Farber, 1970; Wilson, 1940; and others). The high demand which deceleration places on roads in an emergency stop is illustrated in Figure 8.

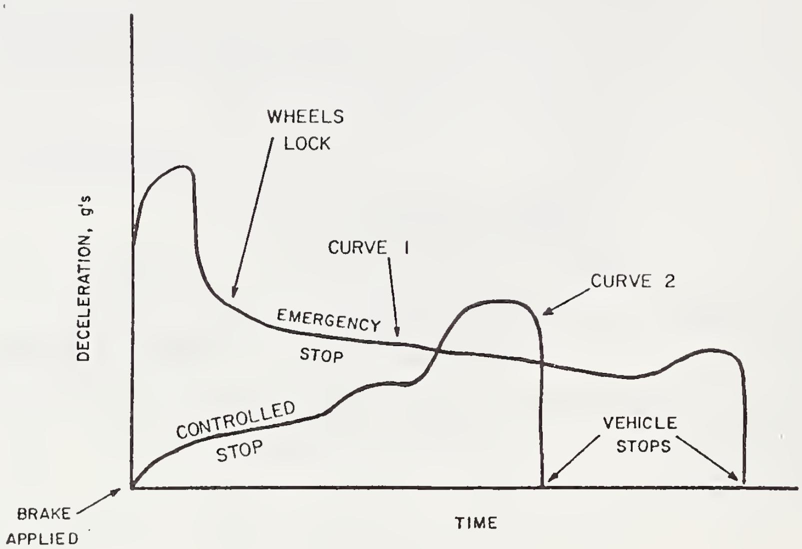


Figure 8. Deceleration patterns for controlled and emergency stops. (Ivey, 1971)

Of the basic maneuvers, acceleration generally imposes the least frictional demand since few drivers try to achieve the maximum level of acceleration of which their vehicle is capable. Further, the acceleration capabilities of vehicles are not as violent as deceleration capabilities. Cornering has been one of the principal concerns of skid studies ever since investigations of skidding commenced. Relationships developed for cornering forces, by functions such as degree of curvature, have indicated that the maximum cornering force of the 95th percentile driver occurs at a curvature of 20 degrees (Taragin, 1954). Recent work has demonstrated that drivers' choice of speed approaching a curve is related to perceived lateral g-forces (Ritchie, 1972). The driver demands resulting from combinations of cornering and decelerating or cornering and accelerating have not been a subject of published literature to date. Studies of these conditions have been confined generally to an examination of tire performance capabilities.

A recent study by the Texas Highway Department (1971) regarding maneuvering along horizontal curves indicated that drivers develop much sharper curvature than the design curvature. In addition to providing information relating to skid hazard, the research is intended for use by highway agencies in developing allowable speed values in regulatory speed zoning during inclement weather.

A number of special driving schools are capable of generating considerable information relative to motorists' reactions in potential (or actual) skidding situations. A race-driving school records g-forces to which their students are subjected in each turn on the track (Van Valkenburg, 1971). The purpose of the record is to show in which turns the driver could have achieved a higher speed and remained below his limiting or "break-away" g-force. There is a tendency for drivers to increase these safety margins as their speeds increase. Another school, the Liberty Mutual Insurance Company Skid Control School, has been innovative in developing a method for educating motorists. The program consists of two parts: a seminar on skid theory and a laboratory session on a practice skid pan. Objectives of the program are as follows:

1. To make a significant contribution to the present knowledge of skid causes so that control measures may be improved.
2. To demonstrate the practicality of skid instruction and encourage qualified traffic authorities and driving schools to undertake similar programs.
3. To make available to the driving public, through printed and visual means, a better understanding of the causes, prevention, and control of skids.
4. To provide a training ground for Liberty Mutual's highway safety engineers, for its fleet policy-holder driver trainers, and certain public agencies concerned with highway safety.

The Skid Control School is an educational technique consistent with a basic approach advocated by researchers at the First International Skid Prevention Conference. A human factors-oriented paper by Forbes (1958) presented at the Conference stressed methodologies to assist the motorist in coping with skid hazards. In addition to the provision of favorable road conditions, highway engineers were encouraged to provide assistance to the driver by means of the following:

1. Driver understanding of basic factors relevant to skid accidents should be promoted by means of widespread advanced driver education. Most public safety education is so general that the majority of drivers do not understand, even in a simplified fashion, the forces and possible results of skidding. Specific and technical information (of the proper level) is needed to prevent overconfidence in and misunderstanding of vehicle, tire, and highway capabilities.

2. Additional sensory cues should be provided to drivers to assist them in evaluating the situation. A device is needed to inform the motorist of hazardous geometry by means of a type of "feed-back" which would enable him to sense vehicle instability through his controls or external vibrations. Another type of cue suggested for the driver involves his sensing lateral forces in traversing a curve. The spiral approaches to sharp curves will be designed to give the driver an off balance sensation from unbalanced lateral forces at a speed below which tire-and-pavement friction will sustain; the driver will feel an uncomfortable side thrust and will tend to keep below the critical speed of the curve. Reports of early experimental tests seem to corroborate the effects of such a design (Stone & Noble, 1940). Use of this type of cue would give the driver a margin of safety, providing he did not meet unusual conditions.
3. Driver education can teach more advanced skills in evaluating highway conditions than it does at present. New techniques are needed to give the driver practice in evaluating a situation involving visual indications of slippery conditions or other skid hazards ahead. One approach is to use driving trainers incorporating moving picture training films and other stimuli. A promising device is the skid simulator currently being developed at the Pennsylvania State University. An operational example of advanced driver education is the Liberty Mutual Skid Control School mentioned above.
4. Training in actual emergency and recovery procedures is needed. It is unfortunate that, for the most part, the general driving public is forced to learn emergency vehicle handling procedures from experience. The two educational procedures mentioned above are a step in the right direction, but no effort has been made as yet to develop the most feasible way of carrying out such training on a large scale.
5. Additional research is needed; too little data exists on how much drivers really know about basic factors involved in skidding. Systematic application of advanced human factors evaluative methods, such as eye-mark camera analysis, can produce substantive knowledge of elements in the driver environment and provide the cues to warn of a potential skidding hazard.

Traffic Signing Considerations*

Subject categories may be developed in the analysis of the literature related to traffic signs and the communication of information to influence driver behavior. The categories include speed zones, speed limits, hazardous conditions, driver perception and driver reaction. Consideration of these categories makes it possible to develop a framework upon which to predicate

*Martin Reiss conducted the literature review pertaining to traffic signing. His contribution is gratefully acknowledged.

documented experimentation intended to minimize adverse driver reaction to high skid potential situations. The review of published research activities which follows provides an overview of relevant signing practice, its potential to convey hazard to the motorist, and its inherent problems.

Speed Zones

Major vehicular thoroughfares with high traffic volume such as transition points on major highways, through streets, and areas of high accident incidence or hazardous conditions leading to high accident potential, can be zoned on the basis of speed. The Auto Club of Southern California (1962) indicated that speed limits should be "realistic" and described a method for determining those limits using an engineering and traffic survey. The qualified effect of establishing speed zones using this criterion was seen as a way of earning the respect of motorists for all traffic control devices hence achieving lower and more uniform speeds. The success of the method was dependent upon the selected speed limit being realistic.

In a survey performed on six highway sections representing nearly 25 miles of the Wisconsin highway system, Mohr (1954) described an evaluation of the effectiveness of speed zoning in controlling traffic speeds and reducing vehicle accidents on rural highways. Both three- and two-lane sections which had been speed zoned for at least two years and had comparatively high accident experience were chosen. Mohr reported that, where the zone limits were determined on the basis of engineering and traffic investigations and where "adequate" speed limit signs were provided and carefully located, there was generally a substantial reduction in the frequency and severity of vehicle accidents. Reductions in accidents, average speeds, and 85th percentile speeds for all motor vehicles were achieved without the use of increased police patrol and enforcement.

Although the concept of creating speed zones seems to promise a significant safety payoff, the techniques for utilizing signing to communicate to the motorist how and when his performance should be altered do not appear clearcut. As previous references have indicated, the first step in the process has been a traffic engineering analysis to determine a realistic safe speed to which the motorist will adhere. Familiarity with an area, geometric configurations, delineation, markings, guardrailing, intersections, and other roadway elements help drivers develop an expectancy of what lies ahead and indicate how they should react to the situation. Good signing which is used to communicate changes in speed limits should work in conjunction with roadway and terrain features, and with other traffic control devices.

There have been several controlled experiments which indicate that drivers do not alter their performance in order to comply with speed zone signing. Maryland (1951) performed a study to determine the effects of speed zone signs and advance speed reduction signs. Speeds for 4,915 vehicles (about 90 percent of the traffic) showed little fluctuation in the average, the modal, median, and 85th percentile speeds, as the result of additional signing. It was concluded that the speed pattern is controlled by roadway conditions rather than by regulatory or advisory warning signs.

The State of California also performed a study to determine the effect on vehicle speeds of a "speed zone ahead" sign and of speed numerals painted on the pavement (Price, 1951). Traffic characteristics measured were: (1) mean speed of all vehicles, (2) mean speed of vehicles traveling above the 85th percentile speed, (3) proportion of vehicles traveling above 35 mph, (4) mean speed inside the zone for vehicles approaching the zone above 35 mph in advance of the zone, and (5) mean difference in speed for vehicles approaching the zone above 35 mph in advance of the zone and inside the zone. No recommendations were made regarding the effectiveness of the devices.

Speed Limits

Several studies on the use of signing to affect driver behavior indicate less than optimum results. When signing violates driver expectancy, apparently the driver adheres to self-imposed speed limits based on observed and expected conditions rather than on posted limits.

Bezkorovainy (1965) examined the influence of horizontal curve advisory speed limits on the behavior of drivers of passenger vehicles on rural two-lane highways. Twelve horizontal curves (from 2 degrees to 12 degrees curvature) served as data collection sites, and statistical analyses (student t, analysis of variance) were used to compare the effects of an experimental standard sign versus no signing for nine testing conditions. During daylight hours and favorable weather conditions, drivers did not differentiate between the signs. Their speeds in negotiating the curves were not related to the posted advisory speed but rather to curve design geometric characteristics. Standard advisory signs (18" x 18") indicating "X" mph, experimental advisory signs (18" x 18") indicating SLOW to "X" mph, and combinations adding a standard curve sign (36" x 36") showed no significant differences in speed at the center of the curve. One item of interest was that, after passing the advisory sign, faster vehicles decelerated at a greater rate than slower vehicles so that as they reached the center of the curve their speeds were the same.

A California study (Hammer, 1968) evaluated the effectiveness of devices similar to those described in the Bezkorovainy study. The "Before-After" study used accidents as a criterion measure of effectiveness. Standard curve warning signs (designated in the MUTCD as W3R or W5R signing) were found to exhibit no significant accident reducing effect. However, when standard advisory speed signs (W46R) were added to the curve warnings, significant accident reductions resulted. The specific accident type impacted upon was the "nighttime single vehicle running off the road". Results were so impressive that the study recommended placing advisory speed signing at every location requiring curve signing. The study further recommended special oversize curve warning – advisory speed sign combinations in severe problem areas.

Brackett (1965) indicated that signing had little influence on the motorist's choice of speed. He further noted that similar findings had been obtained by Rowan and Keese (1961), the California Highway Department (1953), Ottini (1956), and Wiley (1949). These studies are apt to conclude with such statements as:

> "Surveys show that motorists ignore speed limit signs."
>
> "Most drivers are careful and drive according to the existing conditions, not according to the signing."
>
> "Traffic ignores posted speed limits and generally runs at speeds which the drivers consider reasonable."

Wiley (1949) performed an extensive study of the effect of speed limit signs on vehicular speeds. Three sections of through streets were utilized. On two sections, observations coincided with a program of speed limit alteration or removal, while on the third section no speed limits were altered.

Based on his observations, the author concluded that:

1. Traffic consistently ignores posted speed limits, and even in the absence of speed limit signs, operates at speed which the drivers consider reasonable, convenient, and safe under existing conditions.
2. Drivers do not operate by the speedometer but by the conditions they meet.
3. The general public gives little attention to what speed limits are posted.
4. The general public has a false conception of speed.
5. Most presently posted speed limits are ineffective because they are unreasonable and are thereby rendered useless. Their removal would have virtually no effect on traffic and would save large sums of money.

6. Speeds vary little with the time of day.
7. Speeds vary little with traffic volumes up to the point where congestion begins.
8. Adequate speed limits, high enough to cover normal traffic operations and enforced with tolerance sufficient only to meet unusual conditions or to cover the usual inaccuracies of stock speedometers, would probably help expedite traffic and aid in the enforcement of all traffic regulations.
9. Extensive additional studies of this nature are needed to formulate an intensive campaign of education for both the general public and public officials regarding driving speed and speed limits.
10. A sound definition of speed limit should be developed and adopted universally.

An Australian laboratory study (Cameron et al., 1968) compared the effectiveness of various European speed limit signing concepts. The selected measure of effectiveness was motorist's response time to classify a given sign by its function into one of four categories. Significant differences were found among many types of signing. The most noteworthy conclusion in terms of U.S. signing is that symbolic signs were found to be superior to signs displaying verbal messages.

Hazardous Conditions

The foregoing studies indicated that there is benefit to be obtained from creating proper speed zones for specific road conditions and that speed limit signs alone are no guarantee that the driving public will vary its driving performance in the desired manner.

Marsh et al. (1959), in discussing the specific problem of skidding hazard, indicated that drivers should be given clues as to what is ahead. Included among these should be: (1) realistic speed guide signs for sharp curves; (2) warning signs effective day and night for sharp curves, steep hills, dangerous intersections, and traffic circles (these being likely skid locations); (3) reflectorized center, lane, and pavement edge lines, and reflectorized curve delineators; (4) signs warning of pavement which is especially slippery when wet.

Brackett (1964) indicated that the addition of a yellow flashing beacon to existing signing for hazardous conditions (e.g., sharp curves) had "little or no effect" on motorists' speeds. Saccasyn (1951) indicated that lower speeds of freemoving passenger cars are not appreciably lower on wet pavement than on dry pavement. Drivers do seem to ignore a number of indicators of potential hazard. Ultimately we must ask this question: What combination of physical characteristics, signing, and other traffic controls or techniques will cause a significant change in the motorist's speed during his approach to a hazardous condition?

Brackett (1965) undertook additional research to gain inferences regarding a yellow flashing beacon that was activated when ice was present on a bridge. He also conducted an evaluation of a flashing beacon school warning sign. His findings indicated that speeds decreased when the sign was activated, the time for school opening approached, and children were present on the roadway shoulders. Results were incompatible with the icing problem.

Dearinger (1970) investigated potentially hazardous skidding conditions which are created when water lubricates the tire-road surface contact area, the high skid resistance quality of a surface has been worn away, and vehicle speeds are too high for vehicle maneuvers. He presented the hazards in terms of geometrics, weather, and pavement surface conditions; and then suggested various remedial techniques. One of his suggestions worthy of experimental verification is that rumbler pavements can be used to alert the driver to highway sites with high skid accident potential.

Glennon (1971) presented a set of developmental charts for the determination of wet weather speed limits and highway curves. These charts are based on a composite of frictional requirements for passing, emergency stopping, and emergency path-correction maneuvers. Required input information included:

1. number of lanes,
2. shoulder width,
3. minimum stopping sight distance, and
4. skid resistance versus speed relationships.

He advocated the use of wet weather and highway curvature speed limits as a partial solution to the problem of preventing skidding accidents. "It is believed that drivers would tend to comply with limits rationally set for prevailing conditions." By using existing road surface pavement and the aforementioned inputs for a section of roadway, it is possible to derive operational criteria for the wet weather maximum safe speed. In cases where this calculation indicates a wet weather speed limit of less than 25 mph, Glennon felt that the imposed speed limit would be ignored by motorists.

A similar methodology resulting from a followup study (Weaver et al., 1973) was used to characterize two sites in this study. Wet weather speeds were derived using geometric site characteristics (curvature, super elevation, sight-distance) and skid numbers.

The literature suggests that there are certain speeds which the majority of motorists will maintain on many highway sections, regardless of conditions. Where these speeds may exceed the frictional capabilities of the road surface, the solution to the skidding accident problem might consist of a combination of these modifications:

1. Provide signing to communicate wet weather speed limits.
2. Provide skid-resistive surfacing for pavements below some minimum skid resistance level.
3. Provide necessary highway geometry to improve inadequate stopping sight distances and eliminate unexpected curvature.
4. Provide paved shoulders.
5. Provide adequate traffic control devices to effectively delineate curvature.

Driver Perception

Many studies have been performed relative to drivers' perception of signs. Among the variables considered were: sign observation, sign conspicuity, sign color and shape, sign brightness, vehicle speed and position, driver characteristics, and the "importance" or "urgency of information" of the sign message.

A Swedish study (Backlund, 1969) examined the general motorists' detection probability of highway traffic signs. Laboratory experiments simulating traffic conditions produced unrealistic sign awareness, so in-traffic experiments were conducted. Five persons driving along a 170 km stretch of road registered 91 percent of the signs. In an attempt to find to what degree road signs are recalled, 6,000 drivers were questioned regarding the last road sign passed. This procedure took into account drivers' familiarity with the road, experience, exposure, whether or not they had not been interviewed before. The signs were changed at various intervals and degree of road visibility was reported hourly.

Drivers familiar with the road and experiment gave the largest percentage of correct answers. Sign violators gave the lowest percentage of right answers. Sparse traffic tended to decrease driver awareness of signs.

A study conducted in Finland (Eklund, 1968) dealt with factors affecting the conspicuity of traffic signing. Laboratory observations of driver recollections of numerous signs to develop the concept of conspicuity yielded the following conclusions:

1. The brighter a sign or the larger its brightness contrast, the better its conspicuity.
2. The simpler a sign is visually, the better its conspicuity.

3. The more a sign differs from other signs, the better its conspicuity.
4. The more frequently a sign appears on the road, the better its conspicuity.
5. The more obligatory the sign is, the better its conspicuity.

Ferguson (1966), used questionnaires to evaluate driver awareness of sign colors and shapes. He found that there is a direct relationship between driver recognition and the uniformity of signing color and shape. There is a high carryover from traffic signal color since the signals require action and merit attention. Drivers do not pay much attention to or are not aware of particular sign colors. Red, yellow, and white in that order were the colors recognized most often. Shape and message were indicated as the most important sign variables.

Hakkinen (1965) interviewed 2,768 drivers to determine the impact of some signing very similar to that used in this study. Test signing was placed in advance of a curve in the roadway, and motorists were stopped ahead to report what they had recalled of the sign. Speed measurements were recorded for interviewed drivers.

Findings of the report are summarized as follows. The probabilities with which traffic signs are registered by drivers are rather low in ordinary road traffic conditions, and the differences in the registration probability are large. (Here, the term "registration" means that the driver sees the sign and is able to report it in the interview.) The registration percentages were found to be as follows: The "general warning" sign, 28 percent; the "general warning" sign with a supplementary sign "driving control", 62 percent; the 70 km/h speed limit sign, 78 percent; and the 50 km/h speed limit sign, 80 percent.

The speed at which the test sign was passed did not affect the registration probability. The change in action (deceleration) and the registration of the sign were closely interdependent. A large majority of the drivers who failed to obey the speed limit had not registered the speed limit sign.

The driver's familiarity with the road did not affect the registration of the sign *per se*. The groups differed significantly only as far as the registration of the supplementary sign was concerned. The drivers using the road frequently paid attention to the supplementary sign and recalled it more frequently than the other drivers. The distance travelled before the interview did not affect the registration of the test sign. The registration probability for a given driver was not affected by his annual mileage driven. Specific results of correct identification responses for each sign and as a function of driver familiarity are depicted in Figures 9 and 10.

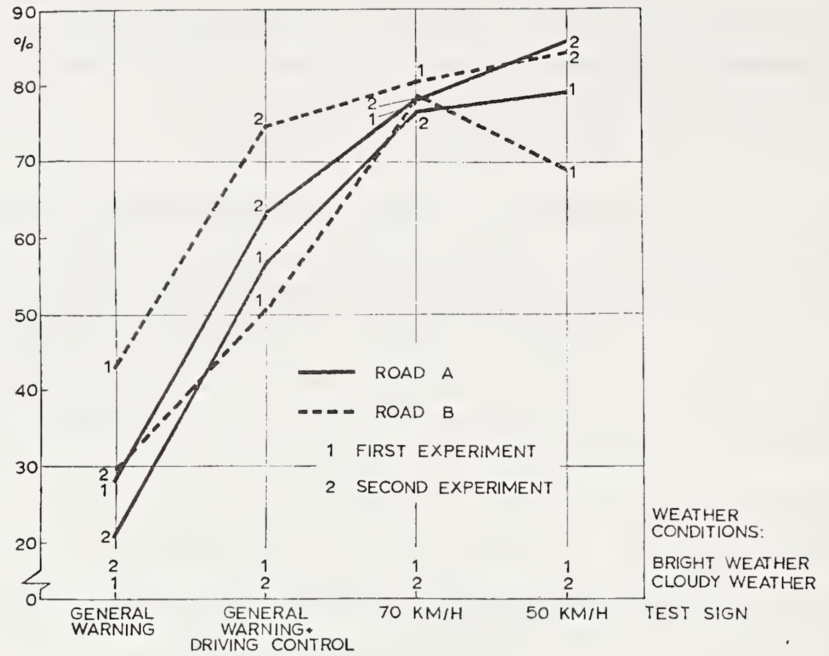


Figure 9. Right answers, by road and experiment.
(Hakkinen, 1965)

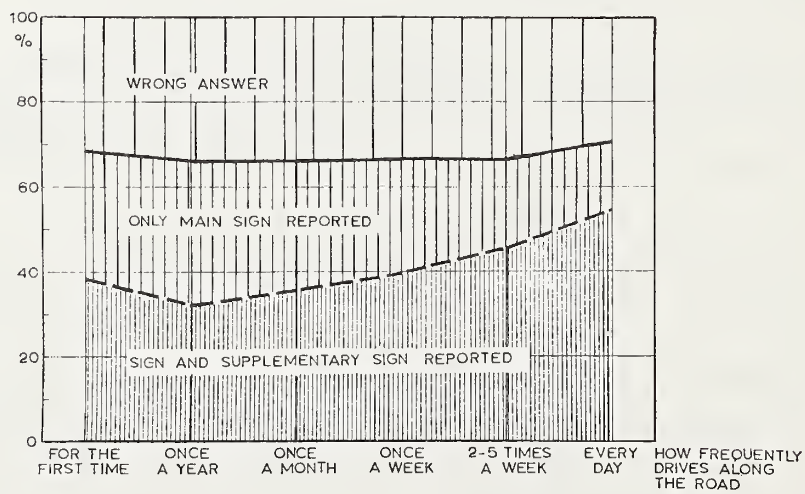


Figure 10. Dependence of answers on driver's familiarity with the road.
(Hakkinen, 1965)

Johannson (1966), in analyzing 1,000 drivers' perception of five different warning signs, found that the percentage of drivers who noticed any one given sign was 47 percent. This fact is postulated as reflecting "urgency of information" based on past experience; that is, the more urgent the information, the more often it is perceived.

Howard (1964) compared drivers' perception to a sign requiring driver action at a number of locations. Some of these locations were chosen so that the sign (sound horn) would make sense, others so that the sign would appear ridiculous. Data were recorded as to response, vehicle speeds and position, occupancy, and sex of driver. An advance warning sign was used in some cases and, as might have been expected, driver perception and response were greater with a replication (the probability of perceiving one sign is 13.9 percent; the probability of perceiving one of two signs is 25.9 percent). Howard concluded that perception of signs increases sharply the more "reasonably" the sign relates to roadway conditions.

Pages (1967) investigated the minimum brightness required for a traffic sign to be seen by the driver in different positions in relation to the sign. This experiment was conducted in a laboratory. In addition to reacting to the sign (slowing down or braking), the driver had to steer the simulated vehicle to keep two vertical bands in coincidence. Typical visual nighttime vehicular signals (white and yellow headlights, blinkers, etc.) were introduced. The findings indicated that the lighted sign is perceived if its brightness is at least equal to that of its surroundings.

A literature review (Svenson, 1968) of motorists' perception of highway signing reminds us that there is a lack of knowledge in the area of warning sign design.

Driver Reaction

Burg (1962) performed a laboratory study to determine the effectiveness of several types of signs, all of which attempted to convey the message that a lane was to be dropped from the road ahead.

A number of observations were made regarding first impressions of traffic signs. They are as follows:

> The first impression a driver receives from a traffic sign is important because the sign message may call for immediate action, or, at least, immediate planning for action. Equally important to the driver who is planning action is an awareness of where this action is to take place. Making a called-for maneuver too soon or too late may result in a situation as dangerous as though no action had been taken. It is for this reason that analysis of the subjects' first impressions took into account implicit or explicit indications of improper timing of the called-for action; i.e., preparing to move to the next left lane. Thus, several categories of response were derived which can be labeled as "potentially dangerous lane-merging actions," such as "immediately slowing down" or "immediately moving into the next left lane" on seeing the sign.

A total of 880 persons saw motion pictures and slides of the signs. The written responses of these subjects revealed a consistent and statistically significant superiority for a 4' x 8' rectangular sign over a number of 40" x 40" diamond shaped signs. The preferred sign read:

Lane End
Merge Left

Jackman (1957) indicated in a study of numerous reflectorized and nonreflectorized "Slow" and "Stop" signs that no combination of Stop sign type and position was any more effective than any other. A Slow sign placed at a location where it was not warranted was ignored by drivers. This gives more emphasis to previous statements regarding violation of drivers' expectancy and the need for "realistic" signing.

Wright (1972) reported on a comparison of the attentional demands of road information transmitted visually and aurally. He indicated that visual messages cause decrement in peripheral vision, that speed decreases, and that tracking errors increase. Auditory messages were shown to have substantial deleterious effects on the more complex, decisionmaking aspects of the driving task.

The general lack of positive motorist response to traffic signing is explained in a study (Williams et al., 1969) that attempts to assess the view of the road user. Whether he finds traffic signs reliable enough to make a habit of altering his driving responses to a sign (without any other information from the road) or whether he ignores them, and to what extent, is determined by motorists' attitudinal verification of the following hypothesis:

> "That instead of accepting the warnings, commands or information presented by road signs, the road user prefers to draw his own conclusions from his observations of the road, and to act on them in preference to the signs."

The hypothesis can best be examined by the replies to the following survey question: "When you know a road well, do you prefer to drive using your own knowledge, rather than the information the road signs gave you? Responses were: Always 38%, Sometimes 47%, Never 13%, No reply 2%.

A review of the work cited in this section indicates that the use of signing by itself is not adequate to obtain driver reactions capable of minimizing the hazards associated with high skid potential locations. Signing, these studies indicate, must be designed as one part of an overall program to accommodate driver expectations and modify behavior through multi-channel messages, repetition, and relevance. Signs should be designed and deployed on the basis of the characteristics of the locations where they are to be used. They should serve as one consideration in the implementation of safety oriented measures such as road surface modification, sight distance improvement, addition of paved shoulders, and improved pavement markings and delineation. One conclusion to be drawn from the literature is that signing should not be attempted without adequate study of other elements in the driver's environment.

Bridge Icing

The problem of ice on bridges is treated separately in this review for two reasons. First, one objective of this study is to examine the effects of various signing schemes to warn of ice on bridges. Second, the mechanics of bridge deck friction reduction due to icing are different from those which govern pavement conditions discussed earlier. This section of the review will examine literature which describes contributory factors of preferential icing on bridges and some remedial signing to warn motorists of the hazard. A survey to determine current icy bridge warning sign usage by numerous state highway agencies is included in the experimental signing development portion of this study. Ice detection, which is a separate and complex subject, will not be covered in this review.

The Hazard

Preferential icing of bridge decks, a well-known but elusive safety hazard, refers to the formation of ice on a bridge deck when the approach roadway may not be icy. It is known that ice will form on any surface if the temperature of that surface is at or below 32°F and moisture in some form is applied. There are two basic ways in which atmospheric moisture can be applied to a surface – condensation and precipitation. Condensation will occur on a surface if that surface is at the saturation temperature of the surrounding air, and the rate at which it occurs when the temperature is at or below 32°F will result in formation of frost on the surface (Roussel, 1973). Precipitation will result in icing if the surface upon which it falls is at or below 32°F. Hence, preferential icing of bridge decks occurs when the bridge surface temperature is at or below freezing and the approach roadway is warmer due to the earth's heating. The most conducive environmental conditions are moderate daytime temperatures, high relative humidity, and sub-freezing nighttime temperatures.

Considerable detailed literature on the preferential icing problem is available. Research has been undertaken to correlate variables of weather, geographic location, and bridge deck thermal properties which lead to preferential icing (Birnie and Meyer, 1970). A study of ice and snow detection and warning system feasibility provides a detailed discussion of physical and meteorological aspects of the problem and then provides an interface with highway department maintenance and warning policies and legal aspects of the problem (Glauz, Blackburn et al., 1971).

Remediation Efforts

Available literature pertaining to preferential icing countermeasures is varied. Numerous documented research efforts have dealt with effectiveness and economics relating to a variety of countermeasures which are listed in Table 2. The scope of this study is limited to signing; however, the table is included to demonstrate the diversity of available countermeasure concepts. A discussion of functional and economic characteristics of various countermeasures is included in the above referenced Glauz and Blackburn study.

Considerable available literature describes ice detection and warning systems which generally include a warning sign as one component of the system (Bourget, 1967; Forbes et al., 1970; Stewart and Sequeira, 1971; Ballinger, 1966; Kentucky, not dated; Ciemochowski, 1968; Ciemochowski, 1969; Glauz & Blackburn, 1971; Idaho, 1971; Birnie & Meyer, 1970; Culp & Dillhoff, 1970; Inoue et al., 1970). However, relatively little effort has been devoted to an evaluation of motorists' responses to the sign (Stewart and Sequeira, 1971; Ballinger, 1966; Culp and Dillhoff, 1970; Glauz and Blackburn, 1971). Ice detector and sign usage remain undocumented in a number of states, and research is in progress in numerous states (i.e., Michigan and Oklahoma).

Table 2

Countermeasures Capable of Preventing, Moderating, or Eliminating the Preferential Icing Hazard on a Bridge Deck

1. Deicing chemicals
   - Sodium chloride
   - Calcium chloride
   - Urea
   - Calcium formate
   - Formamide
   - Others
2. Abrasives
   - Sand
   - Cinders
   - Crushed rock
   - Sawdust
   - Others
3. Salt spreading equipment
4. Electrical-resistance pavement heating
   - Insulated cables
   - Wire mesh
   - Conductive pavement
5. Imbedded pipe with circulating fluid
   - Purchased steam
   - Steam or hot water boilers
   - Heat pump type
   - Naturally occurring warm water
   - Radiation wastes
6. Overhead gas or electric radiant heaters
7. Heating enclosed volumes under bridge deck
8. Warning signs
   - Fixed
   - Optional display
   - Variable message
9. Insulation of underside of bridge deck
10. Plowing and blading

Glauz, Blackburn, et al., 1971

A summary of documented ice warning sign evaluations appears as Table 3. The Colorado study (Ballinger, 1966) examined the operation of two ice warning systems, but it did not include an attempt to study motorists' responses to the signs. However, a noteworthy observation in the report was that signing "inconsistent with prevailing conditions" was generally disregarded by motorists. This observation is compatible with one in the California study (Stewart and Sequeira, 1971) which asserts that static ice or frost warning signs are ineffective because they are continuously visible to the motorist. These two observations, though subjective in nature, corroborate the well documented fact that motorists are more likely to respond to a warning sign in the presence of a perceived hazard (Howard, 1964; Jackman, 1957; Williams and Van der Nest, 1969; Forbes et al., 1970; and others).

Table 3

Documented Motorist Responses to Icy Bridge Warning Signs

Researcher	Measure	Finding
Ballinger, 1966	Subjective Observation	Static signing ineffective — Motorists disregard ice warning signs which are continuously displayed.
Stewart and Sequeira, 1971	Subjective Observation	Static signing ineffective — Motorists do not respond to static signing in place year round.
	Brakelight Application Vehicle Deceleration	Disappointing response — Less than 50% of motorists responded to a flashing "ICY BRIDGE" sign.
Culp and Dilhoff, 1970	Accident Rates	Significant accident reduction — Before and after study of static "WATCH FOR ICE ON BRIDGE" sign at 24 pairs of test and control locations.
Glauz and Blackburn, 1971	Vehicle Speeds Traffic Lane Volume Weaving Brakelight Application Driver Interviews	Varied response — "ICY BRIDGE" with flasher — Sign accounted for average speed reduction of 7 mph. — 65% interviewed motorists saw sign. — Better overall response in presence of hazard.
Kentucky Dept. of Highways, not dated (unpublished)	Vehicle Speeds	Flashing sign effective — 85th percentile speeds were substantially reduced by flashing "REDUCE SPEED-ICE ON BRIDGE" sign.
Arizona Highway Dept. 1971 (unpublished)	Vehicle Speeds	Illuminated sign ineffective — Static "BRIDGE AHEAD" sign combined with illuminated "ICE" panel had little, if any, effect on 85th percentile speeds.

The California study went further and examined motorists' responses to an activated, flashing "ICY BRIDGE" warning sign. Measures of sign effectiveness were the activation of brake lights and vehicle decelerations as recorded by manual observers. Table 4 summarizes the study's observations. The authors state the results as disappointing: motorists' responses ranged from 23 percent to 66 percent. It is noteworthy that significantly higher responses were obtained during conditions of fog and its accompanying reduced visibility.

An accident study of "Watch for Ice on Bridge" signing was conducted by the Ohio Department of Highways (Culp and Dillhoff, 1970). "Before and after" accident reduction rates were analyzed for 24 site pairs, each comprising a test and control bridge location. Signing was placed at test sites during winter months for three consecutive years. Reductions in accident rates were realized at 41 of the 48 study sites; however, significantly greater reductions at test locations were evidence that "driver awareness, attributable to the signing. . ." reduced accidents. Significant reductions were noted for wet and dry conditions, as well as icy conditions. The signing used was identical to the "Watch for Ice on Bridge" sign used in this study, and was similarly placed in advance of bridge locations.

A field evaluation of motorists' response to an "ICY BRIDGE AHEAD" sign was conducted as part of the Glauz and Blackburn study. The fixed message sign, an advisory speed limit panel, and an amber flashing light were mounted on a rotating frame such that it could be displayed to motorists as environmental conditions warranted. Data collected during the experiment included: (1) vehicular speeds, (2) traffic volume by lane, (3) lane change frequency, (4) brake light occurrences, and (5) motorist interviews. Traffic characteristic measurements were made both at the bridge and upstream, with and without the sign. The principal measure, speed reduction between the bridge approach and the upstream location showed a statistically significant reduction during three of four periods when the sign was displayed. Average speed reductions were 7 mph, with larger reductions occurring during periods of localized icing. The data showed no significant effect of the sign on lane distribution at the bridge, although there was a suggestion that the sign caused some weaving from the right lane to the center of three lanes. The data also suggested that, during the condition of localized icing, the warning sign did not increase braking activity on the bridge approach. In fact, drivers were observed to wait and brake after they were on the bridge. However, for the condition of ice or packed snow on the approach, the warning sign appeared to increase the amount of braking on the bridge approach.

Table 4

Driver Reaction to "ICY BRIDGE" Warning Sign

Time	Temp	Weather	Visibility	Driver Reaction							
				Cars				Trucks			
				Deceleration		No. Reaction	% Reaction	Deceleration		No. Reaction	% Reaction
				Brake Lights				Brake Lights			
				On	Off			On	Off		
0525 — 0630	30^{o}	Light Fog	Very Good	1	24	80	24%	3	11	46	23%
0515 — 0635	28^{o}	High Overcast	Unlimited	1	33	42	45%	5	16	51	29%
0750 — 0830	30^{o}	Foggy	1000 ft.	23	72	75	56%	1	22	12	66%
0600 — 0635	21^{o}	Foggy	500 ft.	3	5	5	62%	2	10	10	55%

(Stewart & Sequeira, 1971)

The Glauz and Blackburn study effort also included interviewing a sample of 43 motorists downstream from the bridge. Sixty-five percent advised that they had seen an ice warning sign. The authors break down interview responses as follows:

- Of the 22 drivers who read the warning message:
  - 19 said they slowed down
  - 1 changed to middle lane
  - 1 watched for ice
  - 1 "took foot off the accelerator"
- Of the six drivers who saw the sign but did not read it:
  - 2 said they slowed down
  - 4 did not respond
- Of the 15 drivers who did not see the sign:
  - 4 saw the flashing light at the bridge
  - 11 say nothing at all of the warning system.

Unpublished studies by two state highway departments have demonstrated seemingly conflicting results using 85th percentile vehicular speeds. The Kentucky Department of Highways conducted an in-house evaluation of an alternating message, "REDUCE SPEED," "ICE ON BRIDGE" sign. Activation was provided by an ice detection system, and each of the messages was alternately displayed for two seconds at a time. Speed check studies at the sign location, about one mile from the bridge, showed 85th percentile speeds to be reduced from 65 to 35 mph when the sign was activated. However, no information is available regarding the novelty effect of the sign or its impact in terms of speeds at the bridge. The study concluded that the sign was effective in warning motorists.

The Arizona Highway Department evaluated an illuminated "ICE" panel mounted on a standard "BRIDGE AHEAD" sign. Simultaneous sets of speed data were taken on the bridge approach (in advance of the point where the sign was readable) and on the bridge in order to assess motorists' reactions. The observed speed reductions, noted when the panel was illuminated, were attributed to normative speed variations; and the study concluded that the sign had little, if any, effect on motorists' driving speeds.

In order to assess the documented effectiveness of ice warning signs based on the reviewed studies, some examination is made of common measures used and conclusions drawn. Subjective observations of sign effectiveness by Ballinger and Stewart et al., jointly establish that icy bridge signing should be responsive to the immediate hazard. Inferences from the two studies are that activated signing is necessary for desirable motorists' responses. Driver brakelight indications were used as a measure by Stewart et al., and Glauz et al. Both studies indicate that many motorists wait until they reach the bridge before applying brakes. The measure as a tool for determining response to the sign appears marginal. The Stewart study shows a significantly higher percentage of brakelight activation for poorer weather conditions. Glauz et al., point out that considerable speed reduction takes place without brakelight indications, and that higher braking frequencies prevailed on certain days both with and without sign usage. The inference from these two studies is that brakelight applications are a response to environmental conditions rather than signing.

Vehicular speed data obtained by Glauz et al., Kentucky, and Arizona exhibit both conflicts and similarities. The most marked speed reductions were noted in the Kentucky study; howevcr, as no data were collected at the bridge itself, the results are not compatible with the other two speed studies. The Glauz et al. (average speeds), and the Arizona (85th percentile speeds) upstream and bridge observations compare as follows:

Vehicle Speeds (mph)

		Glauz			Arizona
		Lane 1	Lane 2	Lane 3	All Lanes
Upstream Location	With sign	70.6	75.1	79.1	70.5
	Without sign	71.7	75.1	78.1	73.9
At Bridge	With sign	56.1	60.2	62.7	59.7
	Without sign	63.3	68.3	69.4	66.4
Dif-ference	With sign	14.5	14.9	15.4	10.8
	Without sign	8.4	6.8	9.3	7.5

The data are similar in appearance; however, the study conclusions are in conflict. Glauz et al. found speed reductions at the bridge due to signing to be significant at the .01 confidence level. Although no formal statistical test was applied in the Arizona study, speed differentials due to signing were interpreted to have no meaning because of variations observed in the upstream data. However, it should be noted that the reduction of 6.7 mph observed at the bridge between signing conditions is similar to those recorded by Glauz et al.

The studies reviewed above comprise virtually all available documentation examining motorists' responses to icy bridge warning signs. As the efforts are aimed at the remediation of a severe hazard and do provide conflicting results, it is evident that more research is needed. However, three general icy bridge signing principles can be drawn from the available documentation.

1. *Signing must be Responsive to the Hazard* – Continuously displayed static signing is not convincing to the motorists, due to the time variant nature of the icy bridge hazard.
2. *Highly Conspicuous Signing is Necessary* – A primary factor often dictating motorists' responses to warning signs is the failure to see or mentally register the sign.
3. *Response Eliciting Signing is Desirable* – The warning sign should specify an explicit action. Recommended action should be both responsive to the hazard and realistic. For example, the literature shows that drivers tend to ignore advisory speed limits; hence, "Watch for Ice" would be a more reasonable response.

WARNING SIGNS AND SKIDDING LIABILITY*

The practice of using warning signs to advise motorists of potentially hazardous roadway sections must take into account a possible liability penality to which the responsible highway agency may be subjected. This critical issue is especially timely in view of the emergence of numerous tort liability cases against highway agencies during the past three years. For this reason, the general issue of highway agency liability for skidding accidents is treated here with references to the interface between signing and the liability issue where possible.

The concern that highway agencies have regarding the presence of a skid warning sign increasing their susceptibility to a liability suit is a relevant issue in this study. However, search for legal cases addressing this issue was not very fruitful, as most documented legal opinions imply that prudent usage of signing as an interim warning device rather than a remediation for slippery conditions would uphold the position of the highway agency in a liability suit.

A general review of the agency's legal responsibility for the prevention of skidding accidents is addressed here through a case study of the code in one state. Some recent case studies from various states are then cited to illustrate the highway agency's responsibility to provide skid warning signs.

Skid Hazard Liability

The stated policy of the Federal Highway Administration (Loutzenheiser, 1974) and local highway agencies (Kennedy, 1959 and 1962, and others) is that all practical measures should be taken to provide the motoring public with roadway surfaces that are constructed and maintained such that they exhibit the best skid resistance properties feasible. Policies state that sections of roadway with inadequate skid-resistant properties should also be identified and corrected. All this, of course, is in the interest of accident prevention. Unfortunately, cost, personnel requirements, time, and other constraints prevent the best practices from being put into effect in all circumstances. Skidding accidents do occur and when they do, someone is usually liable.

The legal responsibilities of public agencies toward skidding accidents have not been given much treatment in the literature. It is evident, however, from court cases and governmental

*Gerald Vallette conducted the literature review pertaining to skid hazard liability. His contribution is gratefully acknowledged.

statutes (beyond the limited area of highway agencies) what the agencies are likely to be held responsible for. Two major questions are addressed here:

1. What legal problems might a (state, local) highway agency incur in the process of skid accident litigation?
2. What legal (liability) implications and considerations should an agency take into account in the use of warning signs; e.g., is an agency more liable for a road hazard when it is or is not signed?

At one time, public agencies and employees were generally considered immune from liability in accidents occurring on their property (Carlson, 1974). Their immunity was an outgrowth of the doctrine of "sovereign immunity" which evolved from the "divine right of (the) kings" of England. In medieval times, when a king supposedly received his power directly from God, it was obvious to the people that he was not capable of doing any wrongful act. When the governmental system in the United States was formulated, the doctrine of sovereign immunity was adopted by federal and local governing agencies. The policy has been eroded in recent years by court decisions. A general national trend now is for increasing public entity liability for accidents occurring on public property. As a consequence, changes in governmental statutes appear to have altered the overall view of accident liability. State statutes have been enacted which allow public agencies to be sued "in tort" (for wrongful acts) under prescribed conditions. This "consent to be sued," although limited, leaves the final decision up to the courts for each particular liability case.

Section 53051 of the California Government Code states that a local agency is liable:

> **(a) if it had knowledge or notice of the defective or dangerous conditions (causing the accident), and**
>
> **(b) if for a reasonable time after acquiring knowledge or receiving notice, it failed to remedy the condition or to take action reasonably necessary to protect the public against the condition.**

California Government Code Section 1953, which is concerned specifically with defective or dangerous roadway conditions, elaborates on the criteria which must be met before public entities can be held liable. Many states have enacted governing codes which are similar in content. In many of the states which have not, local courts have sent down down decisions based upon their interpretations of these codes. Section 1953 will be used as an example of a state statute which identifies the circumstances leading to agency liability.

Each of the five points will be followed by a short discussion which relates it to the skidding accident situation. The first point is as follows:

> **No officer of any district is liable (for an accident within his jurisdiction) unless all of the following:**
>
> **(a) The injury sustained (by the plaintiff) was the direct and proximate result of a defective or dangerous condition.**

The plaintiff must first establish that the roadway was in a defective or dangerous condition. Snowy or icy road surfaces would probably not be contested as to the hazardous condition present. Most snowy and icy pavement accidents are not due to the skid-resistant properties of the surface, but rather to the efficiency of highway crews to ameliorate the hazard. Wet-weather, nonfreezing condtions will be considered here. Wet pavements may be harder to establish as dangerous, but when they are coupled with roadway curvature and insufficient warning that the curve may be slippery when wet, sufficient grounds may exist for legal action against the responsible agency.

Second, the plaintiff must establish that the sustained injury was proximately caused by this particular dangerous situation. That is, the wet pavement, or the wet pavement in conjunction with a pre-existing situation, must have been the primary cause of the accident in which injuries were received. Finally, the dangerous condition must have created a reasonable foreseeable risk of the kind of injury sustained. For example, given a wet, curved section of roadway, the possibility of skidding accidents occurring does exist. This final point, therefore, is not likely to be difficult for the plaintiff to establish.

> **(b) The officer (in charge of the public property under consideration) had (actual or constructive) notice of the defective or dangerous condition or such defective or dangerous condition was directly attributable to work done by him, or under his direction, in a negligent, careless or unworkmanlike manner.**

Point (b) has been much debated legally. In order to charge an agency with negligence or inaction, the agency must have had previous knowledge of remedy. The major question, of course, is: What constitutes proper notice of a defective or dangerous condition? Two types of notice are defined. "Actual Notice" is formal notification by agency employees or the public. Actual notice could be in the form of a telephone call to the agency or a letter to the editor of a newspaper identifying some condition that may be contributory to accident causation. Several official complaints of "near accidents" or controlled, nonaccident skids at a site would certainly fall into this category.

"Constructive Notice" is knowledge of circumstances "sufficient to put a prudent man upon inquiry as to a particular fact" where "by prosecuting such inquiry, he might have learned such fact." The rules governing constructive notice require reasonable diligence in making inspections for the discovery of unsafe conditions. This means that the agency has a duty to the public to inspect periodically its property to see that it is in a reasonably safe operating condition. The notice – actual or constructive – must be proven in order to establish liability. If an agency is unable to show that reasonable inspections were made (which would be a difficult position to defend legally), it will certainly be held liable. This nonduty, or nonfeasance, means the duty which the agency (defendant) owes the public (plaintiff). Obviously, public agencies should keep records of all inspections made. The problem also exists that once a dangerous condition has been identified, the agency can still be sued for nonfeasance if no action is taken to remedy the situation.

The most common constructive notice is a series of accidents at a particular location caused by the same condition (e.g., wet pavement). These accidents should have given "a prudent man" sufficient indication that something may have to be done about that location. Constructive notice means, in effect, that an agency "should" have known, even though, in actuality, it did not. If either type of notice exists, the public entity could be held liable for the unsafe condition proximately leading to an accident.

> **(c) (The officer) had authority and it was his duty to remedy such condition at the expense of the State, or at the political subdivision thereof, and the funds for that purpose were immediately available to him.**

State statutes identify which entity is responsible for each section of property likely to be used by the general public. All officers and employees of these entities are generally liable for their own negligent or wrongful acts, or for defective or dangerous conditions of public property created by them within their scope of employment. A plaintiff, in the course of pressing charges, should ensure that he is suing the proper authority if he expects to receive damage payments.

The second part of point (c) requires expansion. Most states require that maintenance funds be budgeted to repair defective or damaged roadways. Naturally, unlimited manpower and funds are not available to any entity. Budget schedules must be made and priorities established identifying the extent to which any one repair should be made. We should realize, however, that while funds are being located or priorities established, states may be spending additional funds in damages in lost court cases. While point (c) establishes only that funds be available, the following point indicates what might be done with these funds.

> **(d) (The agency is liable if:) within a reasonable time after receiving such notice and being able to remedy such condition, it failed to do so, or failed to take reasonable steps to give adequate warning to such condition.**

Assuming that the responsible agency had sufficient notification concerning a potential skid accident site, the question is how much opportunity there was to remedy the situation (time between the notice and an accident), what was done about the condition (adequacy of action taken), or, if no action was taken, why not. Many court decisions have allowed a "reasonable" length of time between the notification and the point in time when the condition should be remedied. The length of the period varies across several decisions and is usually dependent on the variables present in a particular case.

Several methods of ameliorating skid-prone sections of roadway are available. These fall into three general categories: modifying the existing pavement, resurfacing the entire area, and warning the public of the existing situation. The first two methods are desiged to treat the surface and make it more skid-resistive; the third simply warns the public that extra caution should be taken through the hazardous area. All methods are designed to reduce the frequency of skidding accidents.

Modification to an existing surface may be achieved by acid etching, seal coating, and grooving. Grooving is generally considered the best solution and aids both in facilitating water runoff and in roughening the surface. Resurfacing an entire stretch of hazardous roadway in order to roughen a smoothed surface has also been done. The corrective work done by resurfacing, however, must be done properly in order to alleviate the possibility of liability due to negligence. Improper application of a seal coat which results in a surface more skid-prone than the original would surely leave an agency liable for malfeasance – dereliction in the performance of required responsibilities.

The above methods require large amounts of manpower and money. It is unreasonable to expect that a responsible agency will rush out after a skidding accident and groove or repave a section of roadway. Point (d) does, however, leave open the option of giving the public adequate *warning* of a potentially dangerous condition if more permanent repairs are not to be made immediately.

Courtroom discussion on sign adequacy is likely to center on the purpose of the sign, its location, its suitability, and the adequacy with which it warned of the danger ahead. According to the Manual on Uniform Traffic Control Devices (MUTCD), warning signs are to be used whenever it is considered prudent to warn motorists of an existing or potentially hazardous condition. Upon seeing the sign, the motorist should exercise appropriate caution, be it a speed reduction or some such maneuver in the interest of his and others' safety. Warning signs should not be excessively. (Using warning signs to warn of obvious conditions tends to reduce the effectiveness of all signs.) Selection of the particular warning sign should be based on a reasonable judgment by competent traffic engineers. The sign may be as simple as the pictorial "Slippery When Wet" sign, or as stringent as a "Maximum Safe Speed 20 MPH" Advisory Speed Limit sign effective through the hazardous area.

Implicit in the use of warning signs, at least from the standpoint of public agency liability in accidents, is the idea that the signs must be erected at sufficient distance from the hazard to allow the proper action to be executed. The actual advance warning distance should be determined by the prevailing speed and the prevailing hazardous condition. These are manifested in the time available to the driver to comprehend and react to the message and the time required to perform the necessary maneuver successfully. The adequacy of sign placement should be checked during the roadway inspections. Along extended slippery sections of roadway, the sign should be placed in advance of the beginning of the slippery section and at appropriate intervals throughout. The duration of the hazard would certainly dictate the type of sign to be employed.

The use of improper signing may be seen in the following hypothetical but not unlikely situation. A bridge is known to be icy during cold, wet weather conditions, and the agency in charge installs a sign reading, "Watch for Ice on Bridge – When Flashing." If the light is not flashing and a vehicle skids on ice on the bridge, the agency may properly be held liable. The driver could have been justified in not expecting to encounter any ice on the bridge because the sign was in the nonflashing mode. It is assumed in this case that the ice is the proximate cause of the accident. Under nonoptimal weather conditions, agencies using this type of signing would be required to inspect the roadway and utilize the signal if there was any chance of ice being present.

The point being made in this hypothetical situation is that, once erected, signs must be properly maintained. Accidents occurring during times when a sign is blown down, vandalized, not turned on, or in some other manner rendered ineffective, could be construed as having not been signed at all. The type of warning sign installed and its adequacy (including location) could certainly be the subject of litigation. It seems likely, however, that warning sign installation at *known,* hazardous, or high-accident roadway sections would reduce a public entity's liability in a suit brought against it. Several case studies which support this notion are included at the end of this section.

Inaction on the part of a responsible agency is another problem. Accident liability is determined in part, as was mentioned above, by the time and opportunity the entity had to take action. Inaction is also influenced by the agency's weighing the probability and gravity of potential injury to persons and/or property against the practicality and financial burden of the repair. In other words, the agency must weigh the cost versus the benefit of the remedy. While this may be a highly debatable point, it seems that some attempt to ameliorate a situation, even if it is minimal signing, would be more defensible in court than no action at all.

(e) **The damage or injury was sustained while such public property was being carefully used and due care was being exercised to avoid the danger due to such condition.**

The discussion for the previous point may seem to be a gross justification for putting up warning signs at every potential hazardous curve, bridge or other dangerous section. We should remember that the plaintiff bears the burden of proof that the situation was dangerous, that it caused an accident, and that the injury or damage sustained was reasonably predictable prior to the accident. Point (e) is most often used by the public entities in their defense. The plaintiff *must* have used due care in traversing the hazardous section of roadway. Again, the proof of this falls upon the plaintiff. Improper action which was taken by the plaintiff, known as contributory negligence, has been an effective defense in all tort actions under this type of consideration.

In general, there are two types of negligence in an accident situation. Ordinary negligence is the duty owed by the defendant to the plaintiff. This point was discussed above. Contributory negligence is the duty owed by the plaintiff to himself. The motorist is obligated to use reasonable care and prudence for his own safety. If he does not, and this failure contributes to the injury suffered by him, he is precluded from recovery.

Violations of the rules of the road are frequently used as bases for contributory negligence, although others may be used as the particular situation demands. For example, if a driver is able to negotiate a particular curve safely with worn tires at 50 mph during dry pavement conditions, but skids into an accident at 35 mph with the same tires under wet pavement conditions, he may be cited for contributory negligence. The use of worn tires on wet pavements could be interpreted as "asking for" an accident and certainly not as exercising due caution for the conditions present.

Summary

How does all this relate to the questions pertaining to public agency liability posed at the beginning of this discussion? The facts in each accident case generally determine who is liable. Certainly no set patterns can be identified indicating public agency liability in specific situations and nonliability in others. Presumably liability will be assigned to the agency in those cases where the hazardous condition was caused by improper action or inaction. Examples of this type of neglect of duty are pavements worn smooth, improper application of seal coats, or clogged drainpipes causing water to pool on the roadway. However, the public entity may also be held liable when the hazardous condition due to adverse weather creates a danger whose impact could be lessened by appropriate action on the agency's part (e.g., through the use of warning signs). The agency may be considered liable when the proximate cause of the accident is not due to contributory driver negligence. The determining factor will usually be the responsiveness of the agency's actions given the situation involved.

Selected Case Studies

An attempt to cite litigation illustrative of the liability interface between the use of skid hazard warning signs and the general skidding liability issue was not very fruitful, as most cases dealt with broader accident causes. General conditions leading to suits are negligence in the design and maintenance or construction of highways which are shown to be factors contributing to a skidding accident. However, a number of tort liability cases which evolved during the past three years have been definitive of the general role of warning signs (Oliver, 1974). Those cited here were reviewed by Oliver.

In *Hale v. Aetna Causalty and Surety Co.*, 273 So. 2d 860 (La. 1973), the plaintiff claimed negligence for failure to display adequate signing to warn of a reconstruction hazard. The highway department was conducting a resurfacing operation, and an accident occurred in a curved section of highway. The Court ruled that, as a part of the highway department's duty to maintain roads in a safe condition, there was positive obligation to adequately warn motorists of dangers created by the road repairs. Hence, an example of litigation is seen which asserts the highway agency's responsibility to provide signs warning of hazardous roadway conditions.

A skidding accident case, *Weaver v. Lane County* 499 P. 2d 1351 (Ore. 1972), presented the primary issue of an alleged design deficit contributing to an unavoidable collision following a 66-foot skid. In addition, one allegation related to the lack of requirements for signing and other traffic control devices to warn of the hazard. As this case turned out, however, no recovery was made on the part of the plaintiff. The Court ruled that there was no negligence because the allegations all involved discretionary functions.

In action charging improper highway design at a sharp curve (*Catto v. Schnapp*, 298 A. 2d 74, N.J., 1972) the point was made that, although signing warned of the curve, there was no notice for motorists to decrease speed. An expert testifying on behalf of the plaintiff indicated that advisory speed signing should have been used. This testimony, part of an appeal to reverse a prior million dollar judgement against a township, was instrumental in a reversal of the earlier decision on the grounds that this was a discretionary area.

Another case, *Meabon v. State* 463 P. 2d 781 (Washington, 1970), which was concerned with the adequacy of traffic control devices to warn of slippery conditions, addressed the issue of the agency's compliance with the *Manual on Uniform Traffic Control Devices*. The Court, in considering the compliance issue, was forced to take into account that no advisory speed signing was posted.

No recovery was made in the case due to jury questions as to damages incurred. The basis for the decision stemmed from the necessity to give an instruction to the jury regarding the adequacy of warning signs. Reasoning in the case was that the State has a duty to maintain roads in such a condition that they are reasonably safe for travel. This includes responsibility to post adequate warning signs. The question of adequacy is critical in determining liability.

The matter of ice on the highway was addressed in *Walker v. County of Coconino*, 473 P. 2d 472 (Ariz. 1970). No recovery was obtained by a plaintiff charging negligence due to the slippery roadway condition. The Court's decision was based on the fact that ice being present on the roadway does not, of itself, impose liability on the responsible agency. The plaintiff must show duty on the part of the agency, such as was discussed earlier in this section, and then must show failure to comply with that duty. To determine whether the response of the highway agency is in reasonable compliance with his duty, consideration is to be made of: the general versus isolated nature of the icy condition, the existance of actual or presumed notice of the condition, and whether reasonable time for corrective action has elapsed following that notice.

As implied from legal opinions handed down in the few case studies cited here, the use of advisory speed signs to complement existing curve warning signs can serve to substantiate the prudence exercised by a highway agency in providing the safest highways economically feasible. This review uncovered no case where an agency was held liable because of a plaintiff's assertion that the posting of a warning sign was an admission of inadequacy. On the contrary, where agencies have shown discretion in conforming to best practice, the courts were not found to rule against them.

STUDY PROCEDURE

Experimental Design

The basic structure of the experiment is an examination of signing treatments and roadway surface conditions across two situational paradigms. The experimental design has three major dimensions, each an independent variable:

- Surface Condition (varying degrees of pavement wetness and/or skid resistance)
- Signing (warning sign treatments which vary in terms of specificity and conspicuity)
- Situation (combinations of roadway configuration and required vehicle movements which create different driving demands)

The essential task was to determine the signing treatments which produce the most beneficial influences on driver behavior in various skid-risk situations. These treatments are subject to constraints imposed by a number of available site and signing schemes. The experimental objective of the research was to determine the differential effects of signing treatments across varying combinations of driver demand and pavement skid resistance.

The experiment was essentially a variation of the One-Group Pretest-Posttest Design as designated by Campbell and Stanley (1960). The design is widely used in educational research, the basis of the Campbell and Stanley text; however, it lends itself well to the task of determining the effectiveness of highway signing. The One-Group Pretest-Posttest Design consists of an exposure of a group to an experimental treatment. Observed differences are measured in terms of the appropriate parameters during periods of observation both before and after the treatment is administered. Specific treatments for this experiment were skid warning signs as distinguished by their varying levels of specificity and conspicuity. Groups of subjects consisted of motorists at each of the sites selected for the experiment.

A necessary variation to the classical One-Group Pretest-Posttest Design is that the group used consisted of different subjects as each treatment was applied. This study, being a field rather than a laboratory experiment, required the use of subjects who drove through the test sites. The natural assumption which holds true in traditional traffic engineering studies is that driving populations at a given site are identical, holding constant variables such as seasonal effects, time of day, etc. Although the situation was far from ideal, a partial accounting for individual variability was attempted using the driver self-testing analysis discussed in Appendix B.

Some further explanation is necessary regarding the selection of the One-Group Pretest-Posttest Design. The primary disadvantage of this design, when compared to those possible, is that there is no control group observation. There are a number of reasons for selection of this design. First, the choice of another design might have resulted in a confounding variable affecting the experimental-versus-control analysis since it was unlikely that a similar control site could have been located close enough to the experimental site to assure a simultaneous onset of rainfall, a critical factor in the motorists' response to pavement wetting studies. Secondly, the unpredictable nature of rainfall onset posed severe problems of potential resource constraints which rendered the taking of control data impractical.

Because of the general absence of control locations, it is advisable to consider the ramifications from a number of sources of internal validity which arise with the use of the One-Group Pretest-Posttest Design. Although the situation is somewhat different here because of the assumptions regarding the subject population, considerations should be made of the following sources:

1. History – the specific events occurring between the first and second measurement in addition to the experimental variable. The effect of intervening events frequently rivals the hypothesis that the experimental treatment caused the observed differences in the One-Group Pretest-Posttest Design. In this effort, signing conditions were changed simultaneously and data collection techniques were unobtrusive to eliminate any intervening effects which would affect motorists' responses to the signing.

2. Maturation – the processes within the respondents which operate as a function of time per se (not specific to the particular events) including growing older, growing hungrier, growing more tired, and the like. Although maturation is a legitimate error source for the particular design type, it is inapplicable to this experiment because of the varying subject nature of the driving population.

3. Testing – the effect of taking a test upon the scores of a second test. There is no check or correction for a motorist who drives through a test site more than once during data collection unless he is stopped for interviewing. As motorists were selected randomly for interviewing, this did sometimes occur and data on the vehicle were disregarded. Traffic volumes at the sites and number of interviews obtained were sufficient so that testing did not become a significant error source.

4. Instrumentation – when changes in the calibration of a measuring instrument or changes in the observers or scorers used may produce changes in the obtained measurements. Where human observers are used to record observations, there is always a risk of learning, fatiguing, etc. within the observers which produces differences. The data critical in

terms of accuracy (speed, headway, etc.) were recorded electronically, thereby eliminating any chance for error of this type. The use of human data collection was restricted to interviewing and recording gross measures such as rainfall. The majority of the data reduction effort was performed using machine methods.

5. Selection – the biases resulting in differential selection of respondents for the comparison groups. Motorists stopped for interviewing consisted of freely moving vehicles in the traffic stream which were selected at random. A deliberate bias evolved from the fact that the target population consists of the motorist with sufficient gap such that his speed was not affected by other vehicles in the stream.

   It is possible that some experimental bias did result from unknown inherent features sites selected for study. It is believed that such a bias would have no bearing on results as the same condition existed before and after the installation of a new sign. It should be noted that a source of error could have resulted from the fact that respondents were taken from a heterogeneous group of motorists assumed to be of the same population since they were driving through the same site.

   Any study which relies on motorists' interviews is subjected to a bias since certain motorists will refuse to participate because of their time constraints, or for other reasons. As part of our introduction to drivers selected for interviewing, interviewers did stress that the process would take a very short time. About 97 percent of those motorists stopped did complete the interview procedure. There was no reason to believe that there was a differential refusal to be interviewed between the pre and posttest populations.

   The collection of speed data was not subject to selection as an error source.

6. Experimental Mortality – differential loss of respondents from the comparison groups. No loss of respondents was generally experienced because of the unobtrusive nature of data collection. At the point in the site when the motorist was stopped to be interviewed, the speed data were already collected. As noted above, a source of potential bias was motorists' refusing to be interviewed and these data were lost.

The significance of variables measured will be discussed in the later sections dealing with their analyses. However, any treatment of the experimental design must make mention of measured variables and provide an indication of which are most important. As the study examines two separate types of potentially hazardous highway section, it is necessary to define two sets of variables. They are discussed separately.

Wet Pavement

The experimental objective to determine the differential effects of signing treatments across varying combinations of driver demand and pavement skid resistance first entailed selecting the following independent variables and their parameters:

- *Signing* – varying levels of conspicuity and specificity.
- *Pavement Condition* – varying levels of slipperiness due to wetness.
- *Driving Situation* – varying maneuvers of decelerating, cornering, and accelerating.

Selected dependent variables to describe signing effects fell into two categories: vehicle performance measures and motorists' response measures. Specific determinants of each follow:

- *Vehicle Performance Measures* – speed, intervehicle gap, position on roadway, mean acceleration/deceleration.
- *Driver Response Measures* – sign observation, recognition of message and appearance, rating sign as helpful.

A secondary experimental objective, but a primary task undertaken through the questionnaire procedure, was to derive knowledge of motorists' perceptions of potential skid hazard. For this reason, the interrelationships among numerous variables are examined in the questionnaire analysis. They include driver characteristics (age, sex, driving practice, site familiarity, expressive self-testing profile), their observations relating to hazard (assessment of safe wet pavement speed, cue of potential skid hazard).

Icy Bridges

A similar experimental objective to determine the differential effects of signing treatments to warn of a potentially icy bridge, and to make signing recommendations, involved selecting the following independent variables:

- *Sign* – activated or nonactivated, located at bridge or 1,000 feet in advance.
- *Ambient Condition* – daylight or predawn darkness.
- *Bridge Approach* – short or long sight-distance.

Vehicle performance and driver response measures are identical to those cited above.

Skid Resistance Measurement

The literature review identified several sources of variation in the friction obtained between the road and the vehicle. They may be categorized as follows:

1. Inherent roadway properties (composition, macrostructure, microstructure, roadway geometry).
2. Aging factors (polishing of the aggregate by traffic, maintenance condition).
3. Natural environment conditions (temperature, rainfall intensity, snow, ice).
4. Local and accidental conditions (oil spots. gravel, loose soil or sand, leaves, drainage).
5. Vehicle condition (tires, brakes, shock absorbers).

Obviously, this list is complex and, from an experimental point of view, presents an unmanageable number of variations. For this reason, the experiment adopted a simplified set of conditions in which only surface wetness was treated as a variable. Spatially complicating and temporally distributed factors such as temperature (water viscosity), foreign matter and debris on the road (oil, sand, leaves, etc.), and surface deterioration (polishing and roadway breakup) were eliminated to the extent possible. Along the dimension of surface condition or skid resistance, the experimental design has thus been reduced to three roadway conditions: dry and two degrees of skid-resistance degradation due to wetness.

The parameters describing roadway wetness (see Figure 11) are simply dry, wetting, and wet. The dry condition is defined by a pavement which was dry in appearance and it occurred when no rainfall had been evident for a considerable period. The wetting condition describes the first of two conditions of wetness. At the onset of rainfall, the wetting condition emerges and continues until: (1) There is a measurable amount of rainfall; (2) the water film thickness on the pavement is visually detectable; or (3) the rain stops, a reasonable period elapses, and the pavement again appears dry. It follows that the wet condition was in effect when there was measurable rainfall or water film depth on the pavement. The cycle of these conditions and their precipitating events is illustrated in Figure 11.

The wetting condition was difficult to obtain due to problems with weather prediction. Another difficulty associated with the condition is its very short duration; therefore no interviewing was conducted during conditions of wetting. Vehicle speeds in response to the wetting condition were observed in a series of ministudies for various levels of signing.

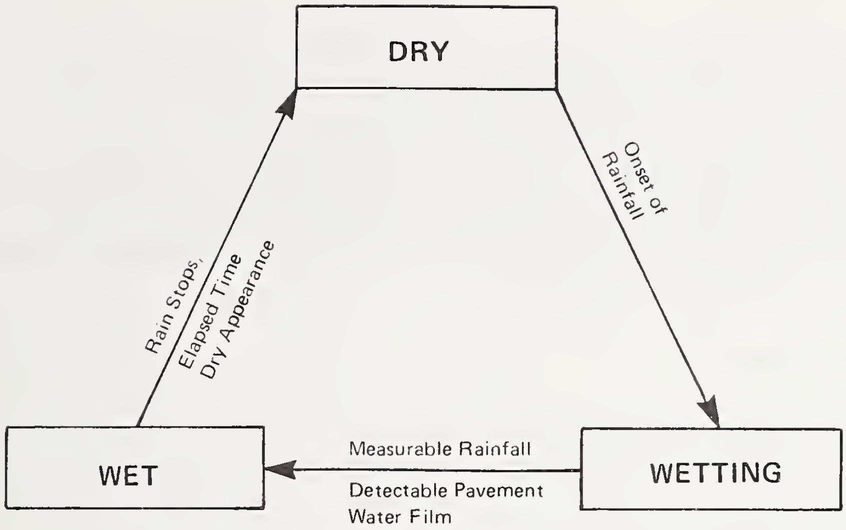


Figure 11. Variables which describe pavement conditions and their associated prerequisite occurrences.

An attempt was made to distinguish between varying degrees of skid resistance which existed during the wet pavement condition. It has been shown that skid resistance theoretically is a function of water film depth which naturally varies with rainfall intensity. That the motorist might be sensitive to these changes was a matter of concern. Therefore, the change in skid resistance throughout wet pavement data collection periods was monitored using a decelerometer mounted in a test car. The decelerometer provided an in-vehicle measure of deceleration experience while skidding on the wet pavement. Its appropriateness as an index of skid resistance evolved from the fact that in-vehicle deceleration is directly perceptible to the motorist. Specifically, the measure would be perceptible to test subjects at the sites in the event of a panic stop. Needless to say, the measure was obtained out of sight of test subjects.

Unfortunately, no changes in skid resistance were detected during periods of wet pavement data collection. The reason is 1) no change in skid resistance occurred because of the controlled nature in which the wet condition was observed, or 2) no change in skid resistance could be detected within the reliability limitation of the measurement technique. There is much support for both reasons. Wet pavement conditions were controlled to the extent that data were collected only during light rainfall intensity amounting to a heavy drizzle (.08 inches per hour) or very shortly after rainfall had stopped and no noticeable pavement drying had occurred. Variation in decelerometer readings obtained for successive runs during which no drying had occurred created a substantive reliability problem. No detectable change in skid resistance based on decelerometer readings was obtained until noticeable pavement drying had occurred and wet pavement data collection had already terminated. Variation in decelerometer readings was not surprising, as measurements can be influenced by (1) design of the test vehicle; (2) location of the decelerometer with respect to vehicle center of gravity; (3) vehicle tire conditions, i.e., inflation pressure, tread wear, and tread type; (4) vehicle suspension system design; (5) shock absorber conditions; (6) vehicle loading factors such as weight and distribution; (7) specific pavement location where test skids are run; (8) grade on which tests are conducted; and (9) braking actions of test driver. Every attempt was made to control variations.

Finally, skid resistance was quantified using the Skid Number (SN_{40}) obtained by a slight variation of the standard ASTM E274-70 method in that three passes instead of five were made with the locked-wheel trailer. The skid number was used to characterize pavement skid resistance properties of two selected sites.

Development of Signing Concepts

Two distinctly different warning sign types were studied; the development of associated signing concepts and variables will therefore be discussed separately.

Wet Pavement Warning

Considerable attention was given to the development of suitable signing prior to its field evaluation. When this project was originally conceived, the FHWA's request for proposals suggested the evaluation of signs which warn of slippery pavements and provide advisory instructions to motorists at four levels of wording specificity. The suggested messages were as follows:

SLIPPERY ROAD

SLIPPERY ROAD – REDUCE SPEED WHEN WET

SLIPPERY ROAD – REDUCE SPEED WHEN FLASHING

SLIPPERY ROAD – MAXIMUM SAFE SPEED X MPH

As the research was undertaken, modifications to reduce the amount of wording yielded the following:

SLIPPERY ROAD

SLIPPERY – SLOW WHEN WET

SLIPPERY – SLOW WHEN FLASHING

SLIPPERY – MAX SPEED X MPH

However, during preparation for field data collection, it became known that one state would not display pavement warning signs with the word "Slippery" due to possible liability problems (the issuc of liability is discussed in another section of this report). The resulting issue then became the adoption of a signing concept that was readily implementable by state and local highway agencies. It was decided that the international symbolic "Slippery When Wet" sign would be used incorporating supplementary panels to convey messages of varying specificity.

Levels of specificity are defined according to the extent to which specific instructions are provided to the motorists advising of remedial action in response to the hazard. Low specificity signing consists of the symbolic "Slippery When Wet" panel with no supplementary wording. Moderate specificity signing which requires some assessment on the part of the motorists, is the display of a "Slow When Wet" panel on a nonactivated sign, or the display of a "Slow When Flashing" panel on a sign with flashing beacons. High specificity signing provides explicit instructions through the provision of an advisory speed limit.

The other primary characteristic studied was that of conspicuity. Simply put, two levels of conspicuity are high and low: the high level is achieved by the addition of two standard yellow flashing beacons to the standard or low level sign. Figure 12 depicts sign conditions which were tested. Six signing conditions range from Condition #1, the "no sign" condition, to Condition #6 which was comprised of high levels of both conspicuity and specificity.

Specificity of the message and conspicuity of the sign were the principal aspects of signing investigated. Therefore, prime attention was given to the testing signing treatments which provided proper tradeoffs between these factors. Other sign characteristics, such as legibility, conformity to established design practice, placement, and so on were held as nearly constant as possible across all signing treatments. Keeping them constant was accomplished by adherence to the standards prescribed in the MUTCD for the determination of all nonexperimental sign characteristics such as letter size and background color.

Icy Bridge Warning

The review of literature reported earlier revealed a rather limited usage of sign wording and formats to advise motorists of the icy bridge hazard. It was therefore apparent that further surveys should be conducted prior to the designation of the specific signing to be used in a meaningful evaluation aimed at the determination of the most promising characteristics suitable to warn of the hazard. Letters of inquiry were sent to numerous highway departments to seek out sign characteristics representative of the state of the art.

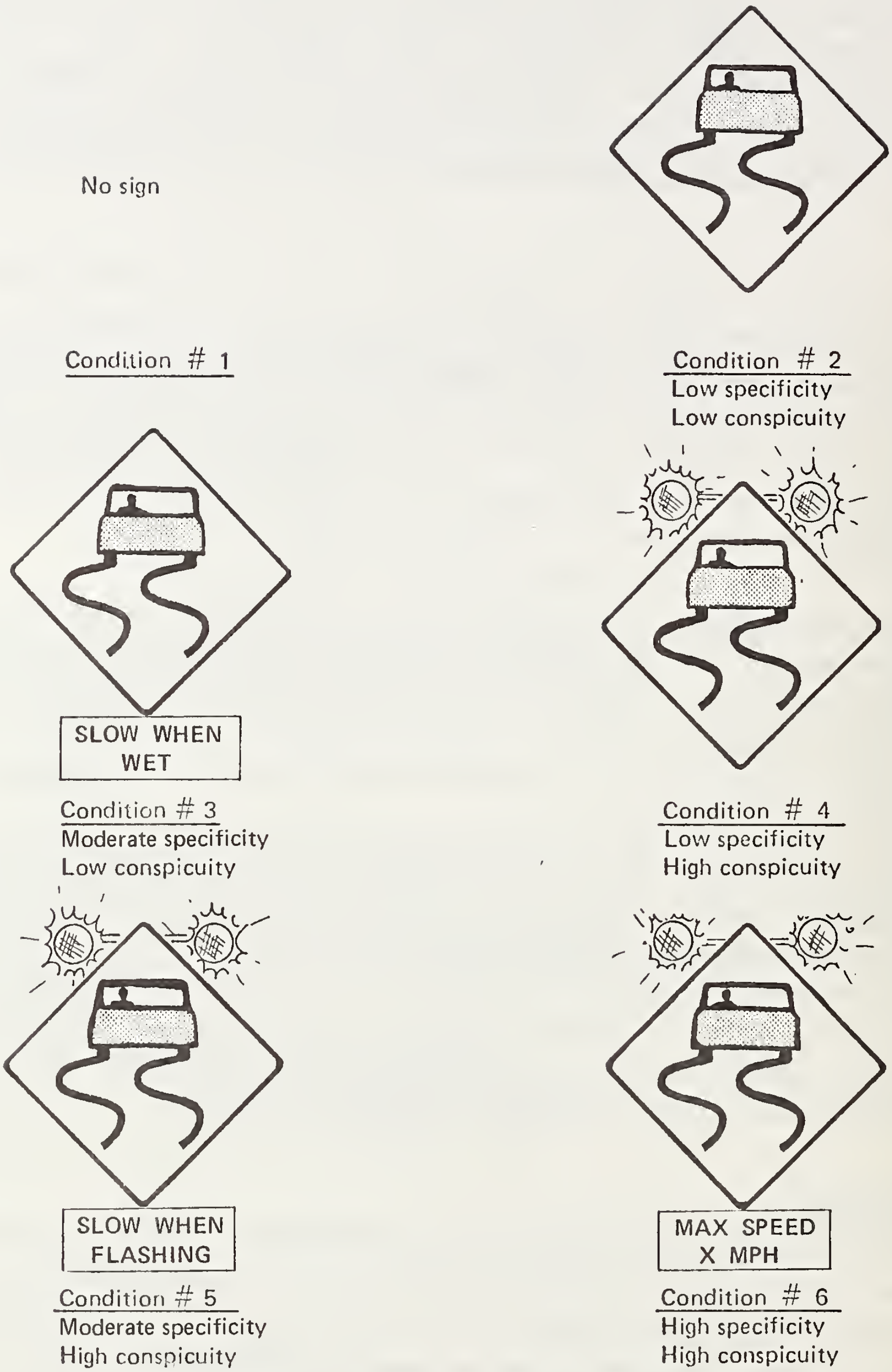


Figure 12. Wet pavement warning signs which were evaluated.

Responses from letters of inquiry combined with information gathered during the literature review provided 24 different sign messages and a diversity of formats. They are listed as Table 5. It was felt, based on the literature review, that activated signing would be more effective than nonactivated. However, after viewing the financial constraints which are necessary considerations of highway agencies, the most promising signs of both types remained as candidates for evaluation. Selected signing concepts from those listed in the table were pretested on the basis of preference rating using twenty subjects, including some who were knowledgeable in highway signing design.

Signing depicted in Figure 13 was selected for field evaluation. Primary sign characteristics studied were activation type and location. Eight combinations of the four signs were used at two bridge approaches to permit comparisons of: activated versus nonactivated, bridge versus advance locations, and short versus long sight-distance approaches. All signs were displayed both singularly and in combinations on both approaches.

The standard diamond 36″ sign was used incorporating 6-inch black lettering on yellow reflective backing. Activated advance signing employed the word "Ice" steadily displayed in brightly illuminated red 6-inch letters. The activated sign at the bridge location used two 8-inch beacons flashing alternately at a rate of 50 times per minute. The bridge and advance signs were located in advance of the bridge at distances of 100 and 1,000 feet, respectively.

Figure 14 depicts photographs of samples of both wet pavement and icy bridge warning signing.

Identification and Characterization of Sites

Two separate site selection processes were conducted, one for each of the two types of skid hazard considered: wet pavements and icy bridges.

Wet Pavement Sites

In order to permit the evaluation of signing treatments under diverse potentially skid-hazardous driving conditions, sites were selected to meet the requirements of distinctly different tire-pavement frictional demands. Three target driver situational paradigms originally designated were: (1) decelerating to a full stop, (2) decelerating while cornering, and (3) accelerating while cornering. During the process of site selection, an assessment of relative driving hazards associated with each driving maneuver led to the elimination of decelerating to

Table 5

Characteristics of Signing Usage to Warn of Icy Bridges

Message	Format	Activation	Documented Usage	Non-Documented Usage
BRIDGE ICY AHEAD	Diamond, black BRIDGE AHEAD on yellow	"ICY" activated by ice detector	Illinois, Michigan, Virginia	Arkansas
BRIDGE ICY WHEN FLASHING	Diamond, black on yellow	Amber flashers ice detector	Virginia	
BRIDGE FREEZES BEFORE ROADWAY	Diamond, black on yellow	Static		Tennessee
BRIDGE FREEZES BEFORE ROAD SURFACE	Rectangular, black on yellow	Static		Pennsylvania
BRIDGES FREEZE BEFORE PAVEMENT	Rectangular, black on yellow	Static		Kentucky
BRIDGES FREEZE BEFORE ROAD	Diamond, black on yellow	Static		Vermont
BRIDGES ICE BEFORE HIGHWAYS	Rectangular, black on silver	Static		Delaware
BRIDGE MAY BE SLIPPERY	Diamond, black on yellow	Static		New Jersey
BRIDGES MAY BE ICY	Diamond, black on yellow	Static		Idaho, Wyoming, Colorado, Nebraska
	With amber flasher	Manual or Ice Detector		North Dakota
CAUTION-BRIDGE FREEZES BEFORE PAVEMENT	Diamond, black on yellow	Static		Connecticut
ICE	Diamond, black on yellow	Static		Arizona
	Rectangular, red neon letters on black	Activated		Oregon
ICY BRIDGE	Rectangular, 8" florescent flashing letters	Ice detector	California	
	Diamond, black on yellow	Manual, folding		South Carolina
ICY-BRIDGE AHEAD	Diamond, black BRIDGE AHEAD on yellow	ICY panel activated by ice detector	Arizona	
ICY BRIDGE AHEAD – 55 mph	Diamond, black on yellow	Amber flashers manually	Missouri	
ICE ON BRIDGE	Diamond, black on yellow	Manual, folding		North Carolina, Missouri, Georgia, Texas, Louisiana
ICY ROAD	Diamond shape neon letters amber flasher	Manually or ice detector	Colorado	
REDUCE SPEED ON ICE ON BRIDGE	Rectangular, 12" letters alternating messages; two seconds each	Ice detector	Kentucky	
SAFE SPEED 25 ICE AHEAD	Overhead illuminated	Manually or ice detector	District of Columbia	
SLIPPERY WHEN FROSTY	Diamond, black on yellow	Static		Minnesota
SLIPPERY WHEN WET OR FROSTY	Diamond, black on yellow	Flare pot or nonactivated	California	
WARNING-ICY SPOTS NEXT MILES	Rectangular, black on orange/yellow	Static		Arizona
WATCH FOR ICE	Diamond, black on yellow	Static		Washington
	Diamond, black on yellow	Manual, folding		Arkansas
WATCH FOR ICE ON BRIDGES	Diamond, black on yellow	Static	Ohio	Mississippi, West Virginia, Indiana, Kansas, Montana
WATCH FOR ICE ON BRIDGES	Diamond, black on yellow	Static		South Dakota
	Rectangular, black on yellow	Static		Virginia

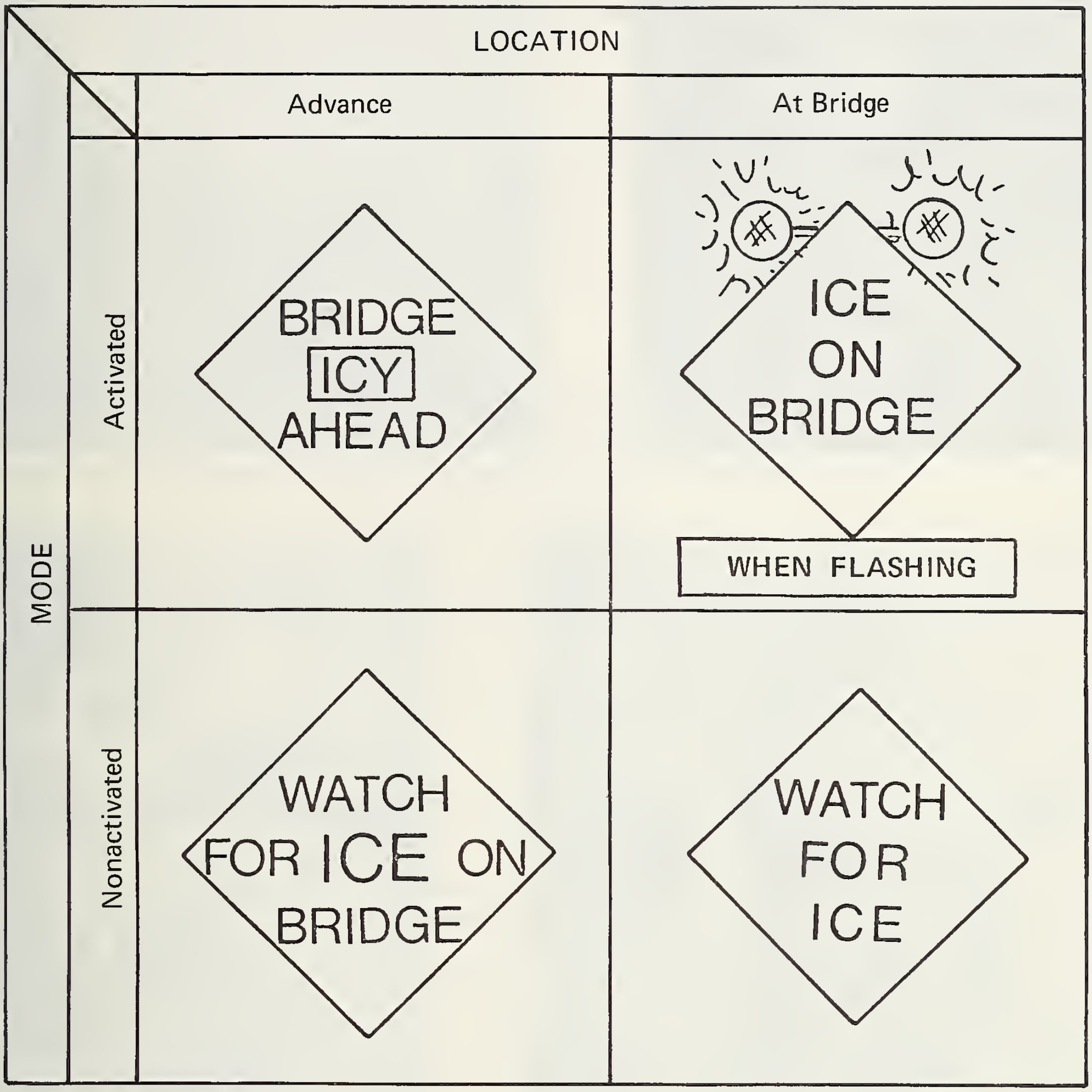


Figure 13. Icy bridge warning signs which were evaluated.

Figure 14. Samples of wet pavement and icy bridge warning signs in place at test sites.

a full stop. Typical of this maneuver would be slowing for stop signs. While deceleration to a full stop places very high frictional demands on the pavement, the consequent low driving speeds rarely contribute to high damage skidding accidents. Likewise, accelerating while cornering is generally executed at relatively low speeds (e.g., merging into traffic) and hazard potential was de-emphasized in the selection of driving paradigms.

The maximum likelihood of a skidding accident is associated with cornering or decelerating from a high speed while cornering. Typical of this latter situation is the approach and maneuver for a freeway exit ramp. The cornering maneuvers studied did encompass deceleration into a curve, negotiating the tight curvature, and acceleration while leaving the tight curvature. Hence, three specific cornering maneuvers observed were sequential decelerating, cornering, and accelerating.

Two paradigms finally designated were (1) cornering, and (2) decelerating while cornering. Specific performance behaviors of both accelerating and decelerating were studied at two cornering sites to permit a verification of findings. One deceleration while cornering site permitted examination of this critical skid-prone maneuver.

Essential site characteristics used as criteria in the selection process were as follows:

1. Environment and roadway geometry to suit the particular paradigm.
2. Low to moderate traffic volume to facilitate roadway tapeswitch operation during rainy conditions.
3. Availability of a suitable motorist interview site beyond sign distance of the tapeswitch array.
4. Level road section for skid resistance measurement.
5. Spatially homogenous pavement type and roughness throughout site.
6. No existing skid warning or advisory speed signs, so as to permit experimental examination of their effects.
7. Good pavement drainage so that puddles will not confound rain driving.
8. No conflicting driving tasks (i.e., merging) to confound driver behavior responses to a potential skid hazard.
9. Available cooperation from local highway authorities and law enforcement agencies.

An attempt was made to include prior skidding accident occurrence as a criterion for site selection. Weaver et. al. (1973) suggests that an annual rate of 20 or more accidents should be indicative of preferred wet weather study sites. Therefore, computerized data provided by the Maryland State Highway Administration describing accident types and causative factors were used to identify 150 candidate sites in the Washington-Baltimore metropolitan area. The most promising sites had to be eliminated as the curves and ramps had already been signed with advisory speed limits, thus eliminating the opportunity to experimentally test their effect. Sites finally selected did exhibit accident histories but to a substantially lesser degree than desirable.

The three sites selected are characterized in Table 6, and site diagrams are presented in Figures 15 through 17.

Site 1, shown in Figure 15, a 20-degree curve on Maryland State Route 108, is the target of primary interest as work (Taragin, 1954) in the literature review noted that maximum cornering forces exerted by the 95th percentile driver occur at a curvature of 20 degrees. Site 1 is further characterized by the determination of a wet weather speed limit for the site using the procedure described by Weaver et al. (1973). Figure 18 from Weaver et al. depicts the lateral friction demand during transversal of curves ranging from .5 to 20 degrees. Skid numbers (SN) are superimposed on the curve by Weaver et al. Their procedure used to establish a critical speed is based on the intersection of the SN curve and the appropriate degree of curvature curve following a superelevation correction to degree of curvature. A plot on the figure, taking into account site characteristics of 20-degree curvature, 11 percent superelevation, and $SN_{40} = 27$, indicates that the critical wet weather speed at Site 1 is about 38 miles per hour.

Curvatures at Sites 2 and 3 did not permit the direct application of the method for determination of critical wet speeds. Therefore, Site 1 was designated as the primary candidate for the evaluation of the effect of selected warning signs, and Sites 2 and 3 were used to verify or refute Site 1 findings based on sign-related speed reductions.

Table 6

Site Characteristics Table

Site Number	1	2	3
Paradigm:	Cornering	Decelerating & Cornering	Cornering
Location:	Md. Route 108 Montgomery County, Maryland	US Route 50 and Palmer Highway Prince Georges County	Pickett Road Fairfax, Virginia
Roadway Characteristics			
Geometry Type	Curve	Exit-Ramp	Curve
Degree of Curvature	20^{o}	28^{o}	115^{o}
Lane Width	11′	20′	11′
Super Elevation Rate	.11ft./ft.	.02 ft./ft.	.00 ft./ft.
Shoulder Width	6′	None	3′
Sight Distance	350′	149′	200′
Pavement Characteristics			
Surface Material	Bituminous Concrete	Portland Cement Concrete	Bituminous Concrete
Drainage	Good	Good	Moderate
Skid Number	$SN_{40} = 27$	$SN_{30} = 55$	Not Available
Traffic Characteristics			
Average Hourly Volume	120	100	150
Average Speed	38 mph	30 mph	22 mph

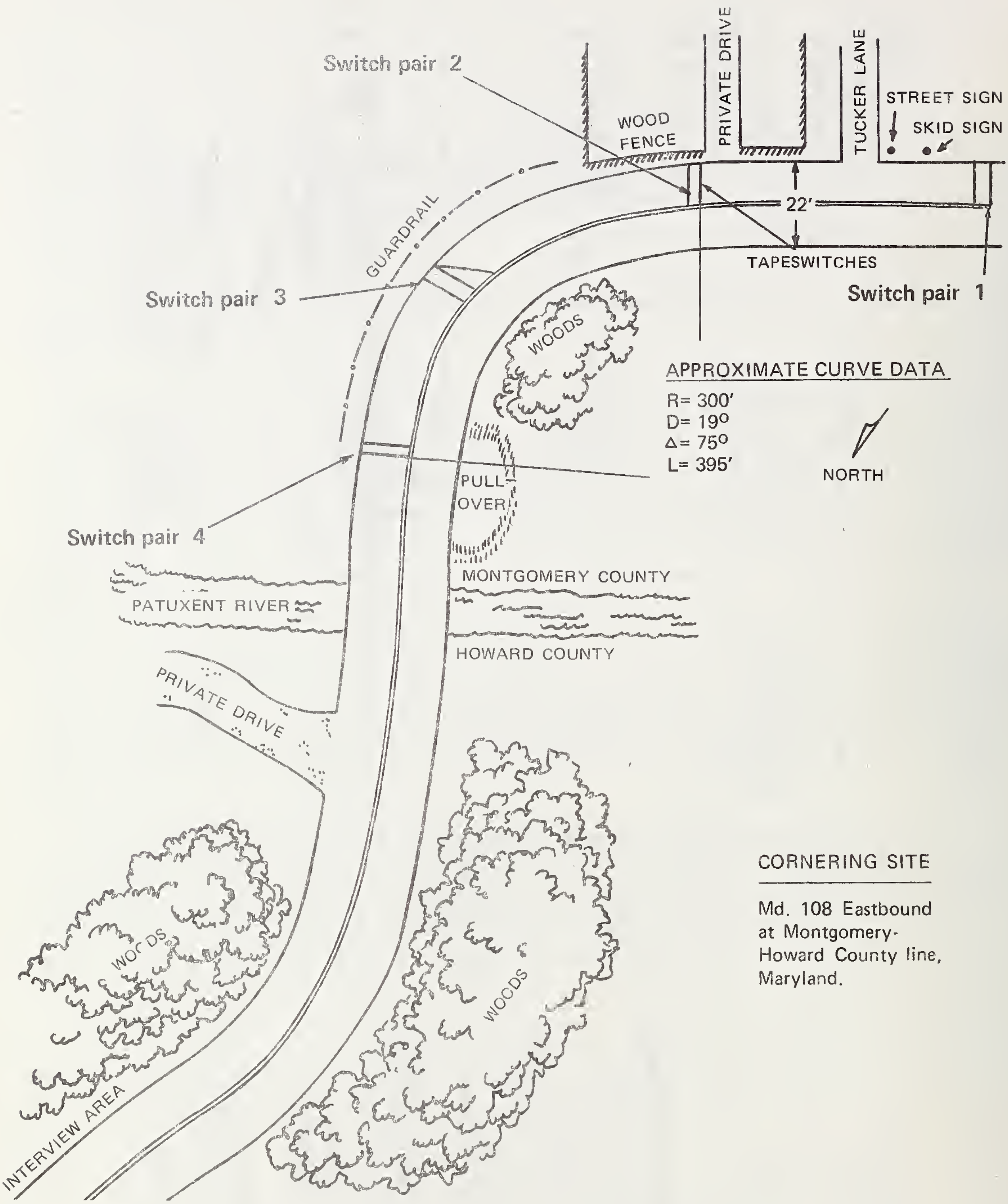


Figure 15. Diagram of Site 1.

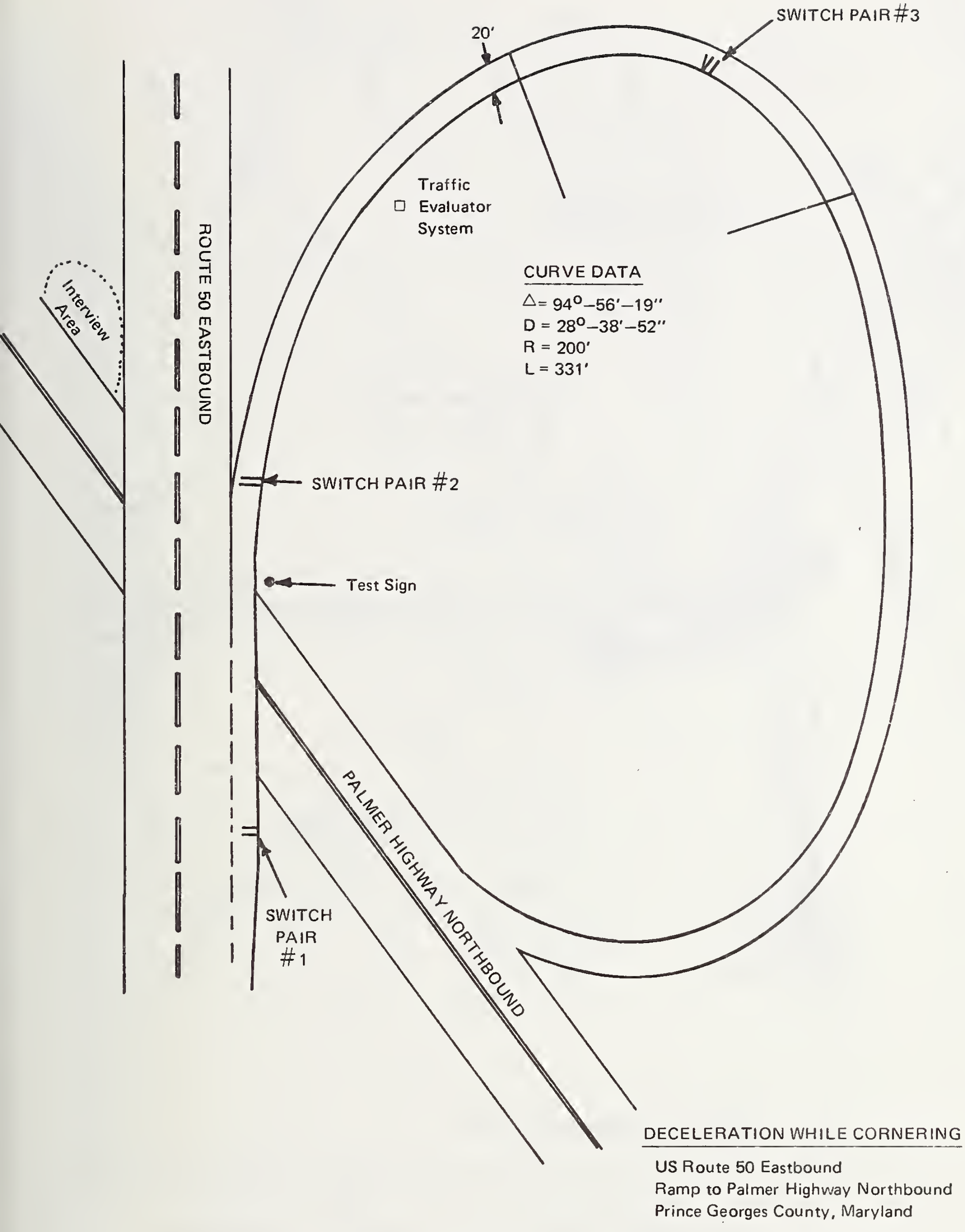


Figure 16. Diagram of Site 2.

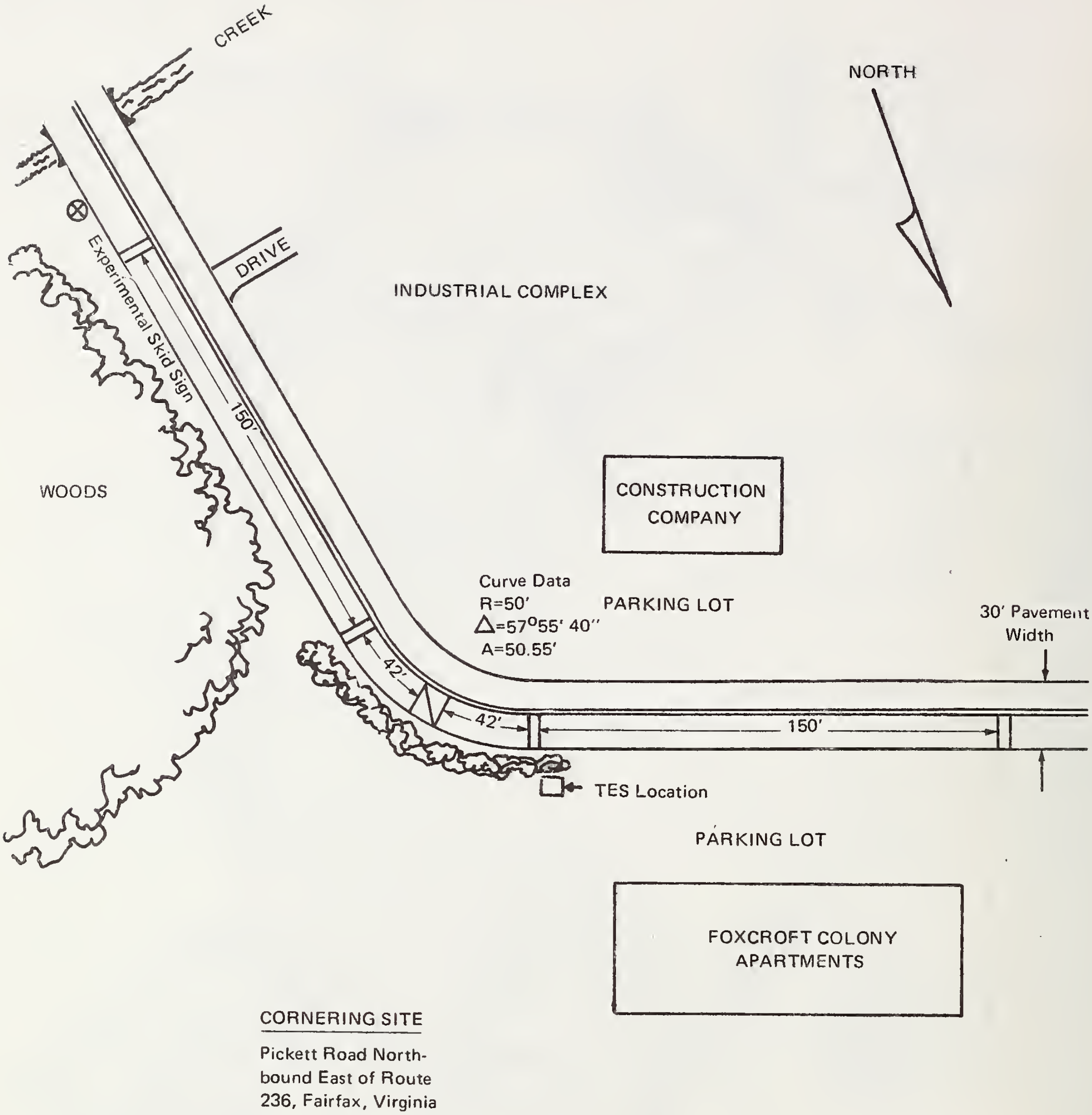


Figure 17. Diagram of Site 3.

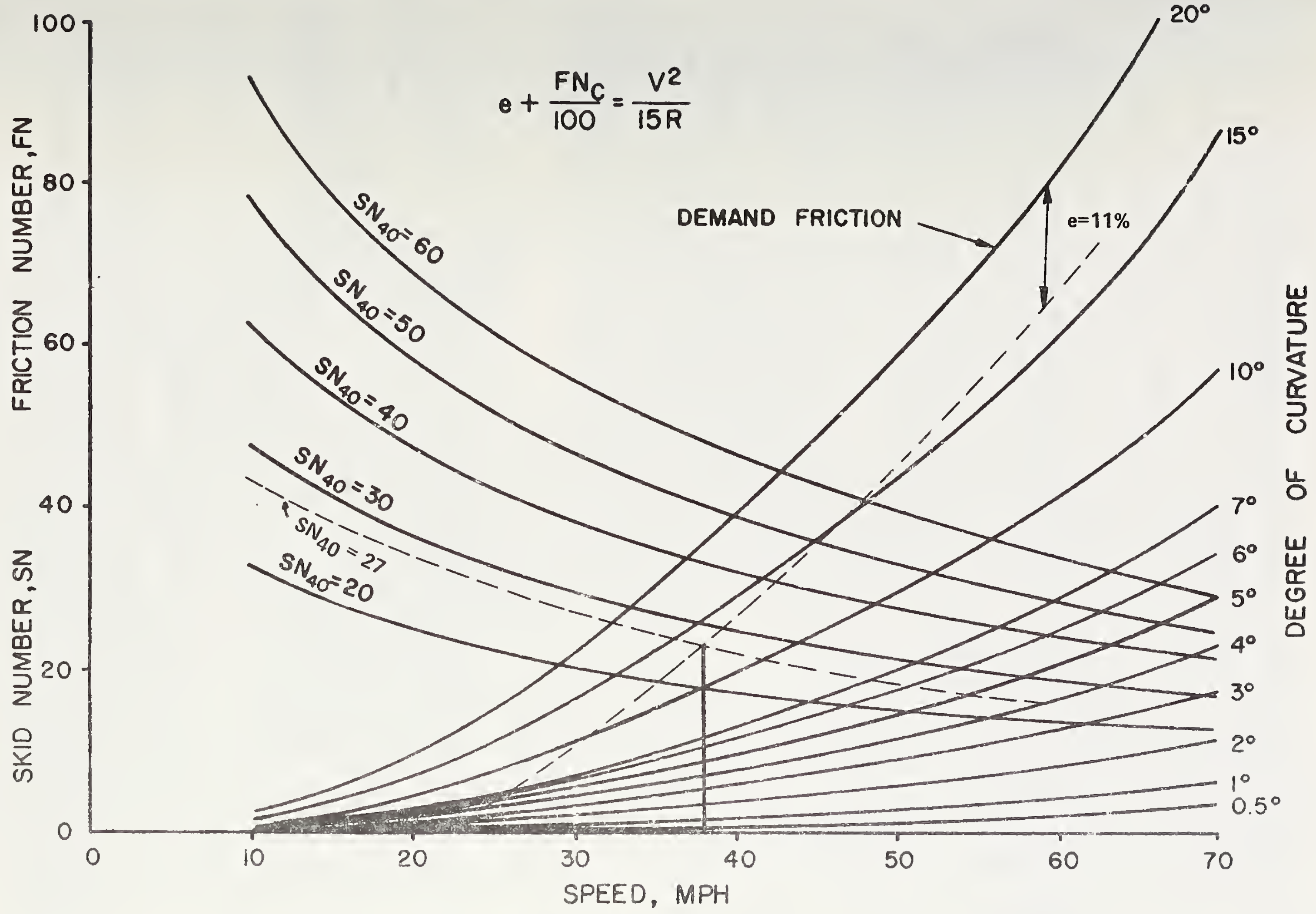


Figure 18. Critical speed on horizontal curves (Smooth transition, zero superelevation)
(Weaver et al., 1973)

Icy Bridge Sites

Site selection strategy involved seeking candidate sites which met certain criteria related to the bridge environment and traffic characteristics. First, the bridge should represent a valid potential ice hazard. That is, the location should be one where the temperature frequently falls below freezing in winter. Certain other bridge characteristics which enhance its ice-proneness were sought. The bridge should be high enough to facilitate rapid cooling beneath the deck, and it is desirable that the bridge be over flowing water throughout the year. Secondly, certain traffic characteristics are necessary for a meaningful evaluation of signing. To obtain a sizable population of unfamiliar motorists in the early morning hours (when there is the maximum likelihood of preferential icing), it is essential to study a well-traveled interregional route. However, the road sensors which were utilized, function best under low to moderate traffic volumes. Hence, the desirable road type was deemed to be a primary two-lane route with no parallel interstate route.

Twenty candidate bridge sites in Virginia, West Virginia, and western Maryland were considered for inclusion into the study. The bridge selected is the U.S. 340 bridge over the Potomac River, 2 miles east of Harper's Ferry, West Virginia (see Figure 19). This location is noted for frequent freezing temperatures because of its elevation. The bridge is two lanes, approximately .4 miles in length, and about 40 feet above the river. U.S. 340, at that point, maintains a sufficient ADT for data collection commencing at 5 a.m., and there appeared to be a suitable number of nonfamiliar motorists. Fortunately, the location was not affected by the reduction of speed limits imposed by the energy shortage.

Sites 4 and 5 were designated as the long sight-distance (westbound) and short sight-distance (eastbound) approaches, respectively. Another bridge 2 miles West on U.S. 340, crossing the Shenandoah River, was used as a control site for data collection on the eastbound approach. Identical approach geometry on that bridge made it a well-suited control site. Further, as the eastbound approach on the control bridge was instrumented, the same sample of motorists was used for testing experimental signing effects at Site 5.

Data Collection Procedures

Two primary data collection techniques were employed. Vehicle performance data were gathered using the Traffic Evaluator System, and driver characteristic data were obtained via questionnaire usage. A discussion of the application and a description of each follows. Figure 20 depicts example usage of each technique.

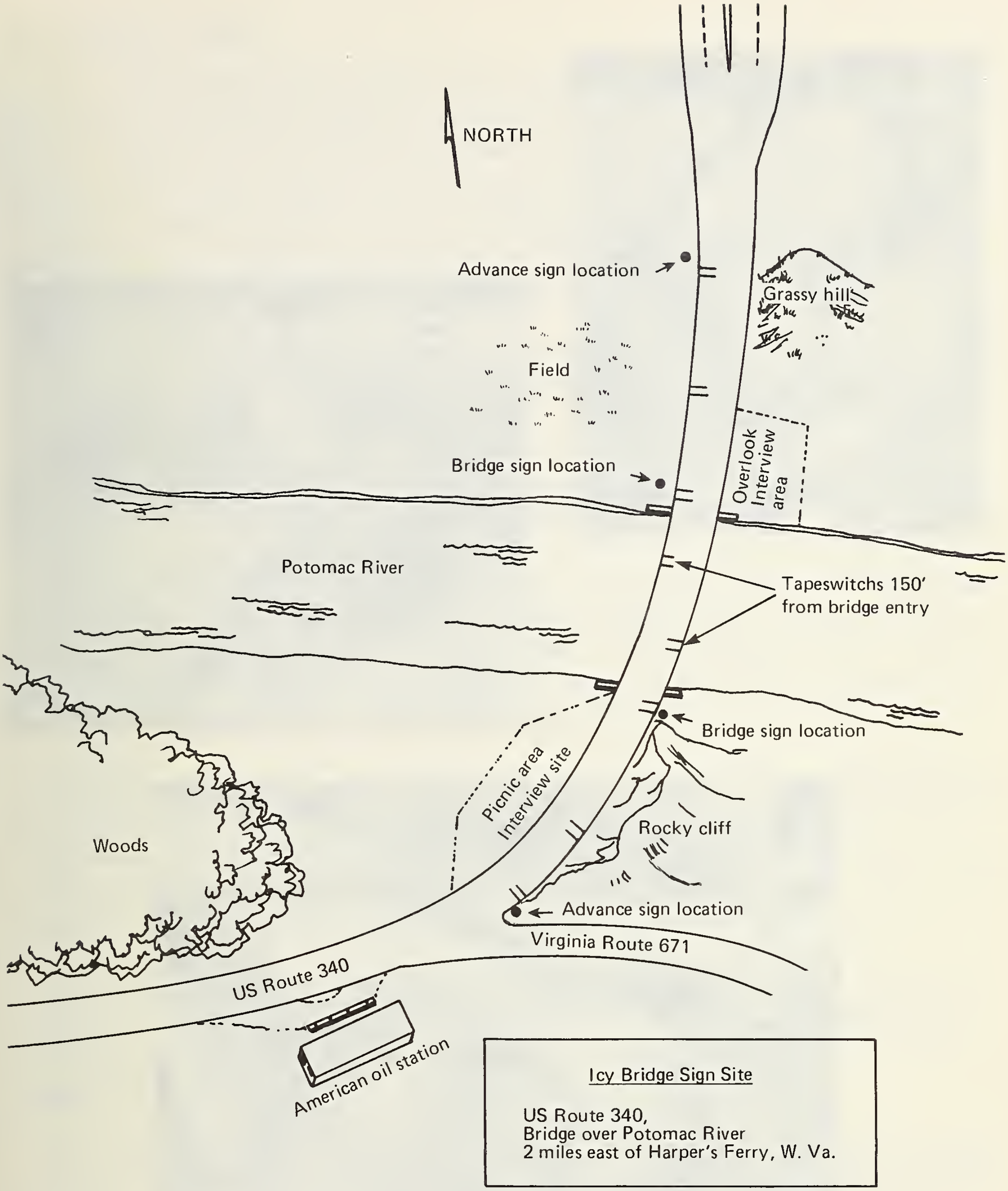


Figure 19. Site diagram for icy bridge signing test site.

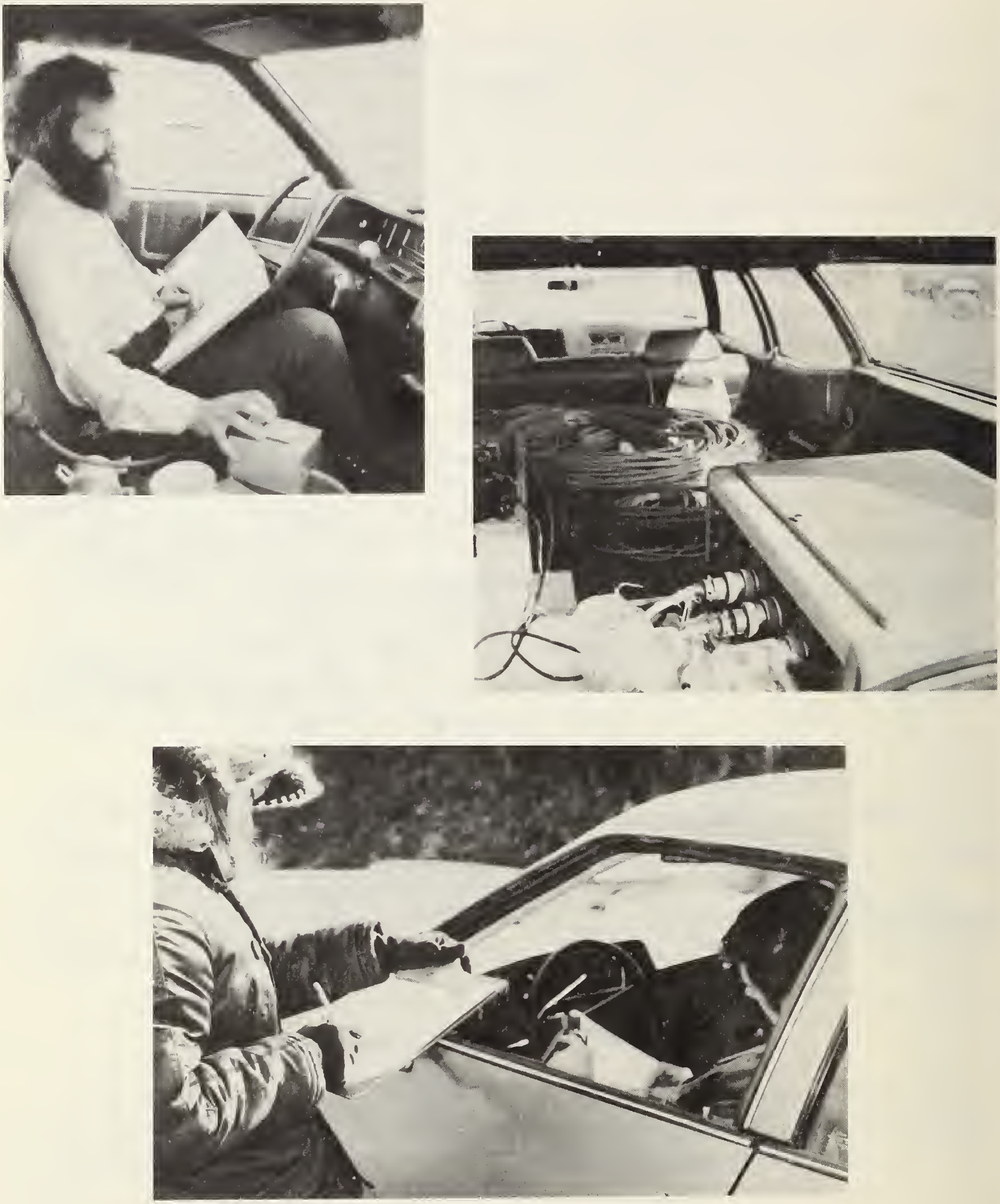


Figure 20. Typical uses of TES and interviewing as data collection methods.

Traffic Evaluator System

The Traffic Evaluator System, property of the Federal Highway Administration, has been successfully used by BioTechnology, Inc. on several studies. Complete information on the system, including hardware, software listings, and a complete description of the use of the system to collect traffic conflicts data, is contained in *Appendices A* and *B* of *Part 2, Volume III: Traffic Engineering Evaluation of Diagrammatic Guide Signs, Diagrammatic Guide Signs for Use on Controlled Access Highways, Report No. FHWA-RD-73-25,* available from the National Technical Information Service, Springfield Virginia 22151.

The system permits low cost collection of precise traffic movement data on extremely large populations. Manual and automatic inputs permit real-time collection of study-related events such as tagging vehicles which are to be stopped for interview, time-related environmental changes such as the onset of rain or accident occurrence, etc. Since all data reduction and analysis may be done by computer directly from the magnetic tape output from the system, results can be processed immediately after the collection of data.

The Traffic Evaluator System does not apply to every situation. Although BioTechnology has successfully obtained data in support of several very different traffic studies, the site and sensor locations must be carefully selected. The primary considerations grow from the way the software identifies vehicles and tracks them through lane changes, turning movements, weaves, etc.; the traffic must not exhibit random stopping behavior.

The Traffic Evaluator System was developed to allow large-scale collection of data pertaining to the operating characteristics of highway traffic. The system records discrete events on magnetic tape. It is a rugged, portable, battery-operated system which can continuously monitor 60 switch contacts. Upon activation of any contact, the time of initial closure and the address of the active switch is written on seven-track computer tape.

The complete Evaluator System consists of an array of vehicle sensors, the evaluator recorder and electronics unit (hereafter referred to as the "evaluator"), power supplies, manual code boxes, associated cabling, and a set of computer programs for reconstruction of the original vehicle characteristics.

The wheels of vehicles are detected with sensors manufactured by Tapeswitch Corporation of America. These sensors consist of two metal strips separated by plastic spacers and enclosed in an extruded plastic jacket. A leadwire runs from one end of each tapeswitch to a terminal box located off the shoulder of the road. When the wheel of a vehicle rolls onto the switch at any point along its length, the metal strips are pressed together and an electrical circuit is completed. The input connections from the switches to the data recorder are such that each switch is uniquely identified. By limiting the length of the switch to the width of a highway lane, the specific lane in which each vehicle is located is automatically identified. The switch is lightweight, about 1/2-inch wide by 1/8-inch high, and causes almost undetectable vibration and noise when crossed by motorists.

The locations of tapeswitches used in this study are indicated in the site diagrams. Sensors are attached to the road with adhesive tape. A double-faced tape the width of the switch is placed beneath each switch and tape with adhesive on one surface only is placed on top of the switch. The combination of two adhesive tapes permits switch deployments to last for a week or more under high-speed, high-density traffic conditions. The single-faced tape on top of the switch provides protection while the double-faced tape between the switch and the highway prevents "creep" of the switch in the downstream direction.

Two utility computer programs and one analytical program are used to prepare data obtained in the field with the Traffic Evaluator System. These programs translate time and switch codes into vehicle and traffic flow histories, reproducing the conditions actually experienced on the roadway.

The utility programs serve only to edit data stored on magnetic tape in the field and to translate these data into a form more readily reviewed by a research engineer. Originally, the data are stored as large blocks of continuous binary bits. These are scanned one bit at a time to locate the first valid time pulse, stored at 0000 followed by an 01 switch code. This operation is used to synchronize the edit program with the data base. Data in each record are then translated from continuous binary bits into elements of three words of six bits each. The first two words, or twelve bits, represent time; the third word represents the switch code.

The edit program also provides the user with a means for selecting specific blocks of field data to be processed by the analytical program. Input controls are provided to specify the beginning and ending file and record numbers of field data which are to be stored for further analysis. Options are also given to print the data processed in octal or decimal and to write the data on magnetic tape.

The primary function of the analysis program is to reproduce the field situation that was originally stored on magnetic tape. This is accomplished by taking axle time pulses and the associated switch codes and producing vehicles at each pair of switches in each lane of roadway.

An important feature of the analysis program is its capability to determine when failures of road switches occurred. Original data which are missing from the input file of times and switch numbers can frequently be reconstructed and used by the program without causing the vehicle to be lost from the output data file. Many internal checks are performed before permitting the reconstruction of missing data, and the output can be used with great confidence.

The program assigns a unique identification number to each vehicle that is recognized entering the array and tracks this vehicle through the entire array of switches on the roadway. As vehicles are determined by the program, the interrelationship of each vehicle with other vehicles in the lane is computed in terms of time and space headway. These vehicle relationships and other space and time measures are output both on magnetic tape and in printed tables.

A number of user-generated input items are provided to permit maximum user control of the data to be processed. Among these are parameters that define analysis periods, locate and identify valid switch codes by lane, and establish ranges and intervals for tablulation of the data. Time and space factors are included for fitting the analysis program to the traffic conditions that prevailed when the data were recorded.

The output of the analysis program is stored on magnetic tape and provides the researcher with the greatest flexibility for conducting many different statistical analyses and tests on the traffic measures. By sorting the data on field with a standard computer utility sort program, any of the fields in a record can be selected as the major control field and any other data in the record as minor control fields, creating any desired set of data for subsequent analysis.

A large number of options is provided in the software. Vehicles may be tracked through an array from one switch pair to the next and output as a single vehicle. Multiple lanes may exist and vehicles may be tracked during lane changes and passing maneuvers. Since the program identifies the number of axles and the included wheelbase of all vehicles at each switch pair, the vehicles may be categorized as motorcycles, compact and standard automobiles, trucks, dual tandem vehicles, vehicles being towed, etc., and special processing may be specified for categories.

A feature of value in some studies is lane position and axle length determination. One or more switches may be deployed at an angle to a pair of parallel switches, and the distance of the wheels from a reference line (curb) can be determined.

Manual observation may be coded directly into the evaluator system and these codes automatically associated with the appropriate vehicle. In this way, observers may be used to tell the system such items as driver sex, number of occupants, vehicle license, state of registration, etc.

After the computer programs have reduced the original switch closures to a reproduction of the behavior and characteristics of traffic in the instrumented segment of highway, the data base may be subjected to appropriate postanalysis using standard statistical programs. Particular vehicle behavioral descriptions printed out in the analysis of data used in this study are vehicle identification number, speed at each switchpair, and whether or not the vehicle was tagged to be interviewed. An example of the printout appears as Figure 21.

Data on two vehicles, one in which the driver was interviewed, are shown in the figure. The first column lists the specific identification numbers successively from the beginning of data collection on a given day. The second column is the period number indicating a particular signing or ambient condition. The following columns are data for various locations in the curve as determined by switchpair number. For example, vehicle 261 is seen to be a 2-axle short wheel-based vehicle exhibiting a speed of 39.24 at the advance location and slowing at the curve entrance to about 30 mph. The motorist moved to the inside more than 5 feet from the edge of the pavement and missed the diagonal tapeswitch describing his position with respect to the edge of the pavement. It is also seen from the printout that he arrived at the advance curve location 3:22:08 p.m. and exited the curve 17 seconds later.

As the vehicle was tagged to be interviewed, the indication appears on the printout. The vehicle's time of arrival and its description, matched with time-lapse film for verification purposes, was used to match questionnaire data with that shown in the above figure. For example, it was shown that vehicle #261 was a Datsun driven by a 30-year old male engineer who did not think the site was a skid hazard. He did see and properly identify the experimental warning sign.

Vehicle 262, shown in the figure, was a larger wheel-based vehicle which was not stopped for interviewing.

Although the foregoing example depicts the procedure used in the slippery pavement study, the same procedure applied to the icy bridge warning effort. An explanation of the questionnaire administration procedure follows.

SKID " SITE 1 " NOVEMBER 27,1973
SIGN CONDITIONS 5 AND 6 " WET PAVEMENT "

VEHID	PD	PR	AX	SPEED	WHBASE	HEADWAY	POSITION	ABS.TIME(MS)	HRS	MIN	SEC	
261	3	1	2	39.24	7.63	7311.66	0.00	55328796.0	15	22	8	
261	3	2	2	29.97	7.56	5957.15	0.00	55332721.5	15	22	12	
261	3	3	2	32.23	7.60	6141.07	0.00	55339123.0	15	22	19	
261	3	4	2	36.24	7.47	6760.16	0.00	55345058.5	15	22	25	INTERVIEW 65
262	3	1	2	39.10	10.12	2362.19	0.00	55369971.5	15	22	49	
262	3	2	2	30.82	10.15	1822.49	0.00	55373899.5	15	22	53	
262	3	3	2	33.36	10.13	1958.06	2.60	55380158.0	15	23	0	
262	3	4	2	33.98	10.12	2107.29	0.00	55386161.5	15	23	6	

Figure 21. Sample Traffic Evaluator System printout used in this study.

Questionnaire

Interviewing of motorists was conducted during the testing of all experimental signing conditions and under all ambient conditions studied. As indicated, speed data for each vehicle were unobtrusively gathered using pavement tapeswitches at various points throughout the curve and matched to the appropriate questionnaire responses for purposes of analysis. Interview sites were located beyond driver sight-distances from the curve. In this way, unbiased speed data were obtained. Vehicles selected for motorists' interviews were those exhibiting sufficient headways such that their speeds were not influenced by others in the traffic stream.

An interviewing strategy was adopted which permitted certain driver characteristic data to be obtained before the driver knew that the study related to potential skid hazard. After a brief introduction which advised the motorist that a safety study was being conducted, general questions were asked to derive his familiarity with the site and the level of his driving practice. More specific questions were then asked regarding his assessment of the posted speed limit and his estimation of safe driving speed at that site during wet pavement conditions. By this time, the motorist knew the study pertained to potential skidding maneuvers. Questions were then asked regarding his skidding experience both at the site and within his overall driving experience. The driver was asked whether or not he thought the site was a potential skid hazard and, if so, what his cue of the hazard was. In cases where the experimental sign was not cited as the cue, the driver was asked if he had seen a sign warning of a possible skid hazard. If he had, he was asked to identify the sign by describing its appearance and message and to rate the sign as being helpful or not helpful.

The verbally-administered portions of the interview outlined above took about 4-minutes per vehicle. Cooperative drivers were asked to fill out a short attitudinal questionnaire to determine their expressive self-testing profiles. The form was accompanied by a disclaimer stating that the answers were to be used for research purposes only. The questions pertained to the driver's feelings about driving fast on two-lane rural roads, about passing while driving at high speeds, about proneness to calmness or panic in the event of an unexpected skid, and to the driver's rating of the site as being dangerous as a skid hazard. Answers to these questions were placed on a plus-to-minus scale to provide uniformity of analysis.

While motorists filled out their portion of the questionnaire, the interviewer recorded data descriptive of the vehicle and driver.

Questionnaire information with matched vehicle speed data was coded onto punched cards and classified by variables which are discussed in a later section dealing with questionnaire results. Samples of the questionnaire forms are found in Appendix A. Appendix B is a discussion of questionnaire results pertaining to the expressive self-testing analysis, and Appendix C (a limited distribution volume) contains a complete computer printout of the questionnaire analysis.

ANALYSIS AND RESULTS

Study results pertaining to both the effectiveness of warning signs and motorists' general awareness of two potential skidding hazards are discussed. Vehicle performance results obtained with the Traffic Evaluator System in response to potentially slippery pavements due to rain and potentially icy bridges are covered first. This is followed by a discussion of questionnaire findings for each hazard.

Traffic Evaluator System Data (Wet Pavement Conditions)

As mentioned in the preceding section, the Traffic Evaluator System (TES) was used to collect detailed information on vehicular trajectories. Specific measures derived from the TES were vehicle speeds, accelerations, lateral placements, and intervehicle gaps. The literature has overwhelmingly demonstrated the importance of speed as an indicator of skidding hazard. Hence, speeds of individual vehicles became the primary TES measure of effectiveness used to examine motorists' responses to varying hazard situations and experimental warning sign conditions. Aggregated vehicle accelerations, gaps, and placements were not seen to be sensitive motorist skid hazard responses. However, individual intervehicle gaps were used for selecting free flowing vehicles for speed analyses. Lateral placement of vehicles was seen to be related to vehicle flow in the opposite direction; it was therefore not useful. Mean accelerations were examined across driving situational paradigms and hazards imposed by ambient conditions, and some differences were noted.

Three classifications of speed study were used to examine driver reactions to potentially hazardous conditions. First, a general evaluative study examined response differences as a function of the six experimental warning sign conditions. The signs were tested at three sites during daylight hours under conditions of wet and dry pavements. Secondly, a similar study took into account the effects of increased conspicuity obtained from use of the flashing signs during hours of darkness. Thirdly, a series of ministudies examined motorists' responses to the onset of rainfall under various experimental signing conditions.

General Warning Sign Effects

As pointed out in the section dealing with site characterization, Site 1 is representative of a potentially severe wet pavement skidding hazard. Therefore, a thorough examination of all signing conditions was conducted at Site 1, followed by an attempt to confirm observed effects at Sites 2 and 3. Three types of sign evaluative data were collected:

- *Normative* – unobtrusive, no signing, dry pavement, throughout all times of day to determine normal driving patterns.
- *Dry Pavement* – both with and without signing to determine dry pavement effect.
- *Wet Pavement* – both with and without signing to determine wet pavement effect.

It was obviously necessary to collect data during both dry and rainy weather. The need for uncontaminated driver responses and the unpredictable nature of rainfall occurrence jointly dictated the order of data collection. Wet pavement data were collected first on an opportunistic basis as weather permitted. Then, following a reasonable period to allow familiar motorists to dismiss any primary recollection of the signing, dry pavement data were collected.

Site 1. Wet pavement data were collected at Site 1 for all experimental signing conditions during two attempts occurring three weeks apart. In each case, light rainfall began prior to the data collection period and terminated during the procedure. Pavement slipperiness was monitored using the decelerometer technique in an attempt to monitor the effects of rain stoppage. In one case, data collection was terminated because of darkness, and in the other because of pavement drying.

On 5 November, four sign conditions were tested. On 27 November, the remaining two conditions were tested, and additional data were collected for the "no sign" condition to assess compatibility with data taken on 5 November. The two-day effort provided speed and placement data for over 500 vehicles passing the site during wet pavement conditions.

Tables 7 through 9 provide summaries of TES wet pavement data gathered at Site 1. Average speed data are seen to be affected by the presence of various sign conditions. Significant reductions in mean speeds between the "no sign" condition and all activated signing schemes (i.e., those which incorporate flashing lights) were observed on the curve approach in the tight curvature. The magnitude of speed reductions is small (less than 5 mph), yet the sample does illustrate differential effects which are significant at the .05 level. Table 9 compares "no sign" data collected for each day which showed no significant mean speed differences in an attempt to establish compatibility between the data sets.

Table 7

Summary of Data Collected November 5, 1973, Under Condition of Wet Pavement
(*Indicates significant difference from "no sign" situation: $a \leqslant .05$)

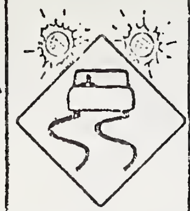
	No sign Condition # 1	 Condition # 2	 Condition # 3	 Condition # 4	
NUMBER OF VEHICLES =	60.	45.	57.	59.	Switchpair #1 (200 feet before curve-sign location)
MEAN SPEED, MPH=	40.85	39.67	39.51	37.34*	
STD. DEV. SPEED =	5.97	3.78	6.43	5.68	
MEAN INTERVEHICLE GAP, FEET	2700.26	3278.51	2173.18	2292.64	
STD. DEV. GAP =	3168.35	3672.31	2310.86	2278.40	
MEAN ACCELERATION, F/S/S=	-.88	-1.12	-2.17	-1.50	
STD. DEV. ACCELERATION =	5.55	3.48	3.43	6.25 *t=3.27	
NUMBER OF VEHICLES =	64.	41.	56.	59.	Switchpair #2 (entering curvature)
MEAN SPEED, MPH=	35.86	36.36	34.57	32.94*	
STD. DEV. SPEED =	6.15	5.61	5.14	5.26	
MEAN INTERVEHICLE GAP, FEET	2288.01	3314.48	2037.39	1997.65	
STD. DEV. GAP =	2830.69	3533.80	2254.31	1975.90	
MEAN ACCELERATION, F/S/S=	-1.42	-2.07	-2.31	-.87	
STD. DEV. ACCELERATION =	5.06	4.28	3.18	5.98 *t=2.84	
NUMBER OF VEHICLES =	64.	42.	58.	57.	Switchpair #3 (tight curvature)
MEAN SPEED, MPH=	34.88	35.33	33.60*	33.19*	
STD. DEV. SPEED =	4.64	3.66	3.60	4.05	
MEAN INTERVEHICLE GAP, FEET	2229.69	3201.37	1986.33	2127.99	
STD. DEV. GAP =	2746.40	3395.91	2139.84	1995.39	
MEAN ACCELERATION, F/S/S=	-.05	.94	.37	1.02	
STD. DEV. ACCELERATION =	4.35	2.54	1.85 *t=1.71	6.82 *t=2.14	
NUMBER OF VEHICLES =	63.	42.	58.	56.	Switchpair #4 (leaving curve)
MEAN SPEED, MPH=	34.41	36.03	34.44	34.16	
STD. DEV. SPEED =	7.62	3.53	4.35	4.39	
MEAN INTERVEHICLE GAP, FEET	2286.10	3292.15	2024.65	2205.48	
STD. DEV. GAP =	2787.94	3512.99	2200.96	2135.52	
MEAN ACCELERATION, F/S/S=	1.23	-.14	1.11	1.41	
STD. DEV. ACCELERATION =	5.30	3.16	2.65	7.54	

Table 8

Summary of Data Collected November 27, 1973, Under Condition of Wet Pavement
(*Indicates significant difference from "no sign" situation: $\alpha \leqslant .05$)

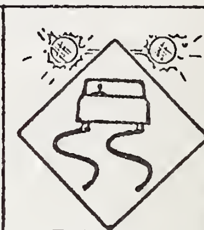
	No sign Condition # 1	 SLOW WHEN FLASHING Condition # 5		 MAX SPEED X MPH Condition # 6		
NUMBER OF VEHICLES =	68.	50.		54.		Switchpair #1 (200 feet before curve-sign location)
MEAN SPEED, MPH=	39.37	35.62*		35.73*		
STD. DEV. SPEED =	4.71	5.43		5.02		
MEAN INTERVEHICLE GAP, FEET	951.74	1584.32		2380.33		
STD. DEV. GAP =	1163.67	2077.79		2423.66		
MEAN ACCELERATION, F/S/S=	-.79	-1.46		-2.25		
STD. DEV. ACCELERATION =	2.62	2.90	* t=3.92	2.89	* t=4.09	
NUMBER OF VEHICLES =	68.	49.		56.		Switchpair #2 (entering curvature)
MEAN SPEED, MPH=	35.07	31.51*		30.16*		
STD. DEV. SPEED =	4.22	4.15		5.40		
MEAN INTERVEHICLE GAP, FEET	848.48	1413.98		1830.53		
STD. DEV. GAP =	1032.54	1868.29		1884.37		
MEAN ACCELERATION, F/S/S=	-1.16	-1.36		-.70		
STD. DEV. ACCELERATION =	4.95	2.30	* t=4.55	3.25	* t=5.44	
NUMBER OF VEHICLES =	67.	49.		57.		Switchpair #3 (tight curvature)
MEAN SPEED, MPH=	34.29	32.47*		31.89*		
STD. DEV. SPEED =	3.43	3.32		3.56		
MEAN INTERVEHICLE GAP, FEET	821.66	1503.49		1910.81		
STD. DEV. GAP =	1014.67	2073.50		1915.50		
MEAN ACCELERATION, F/S/S=	.40	.67		.21		
STD. DEV. ACCELERATION =	1.97	1.48	* t=2.87	1.62	* t=3.81	
NUMBER OF VEHICLES =	66.	50.		57.		Switchpair #4 (leaving curve)
MEAN SPEED, MPH=	35.72	33.45*		33.44*		
STD. DEV. SPEED =	3.88	3.54		4.39		
MEAN INTERVEHICLE GAP, FEET	887.00	1544.54		2004.89		
STD. DEV. GAP =	1132.70	2149.82		1917.78		
MEAN ACCELERATION, F/S/S=	-1.66	.17		.95		
STD. DEV. ACCELERATION =	17.19	2.53	* t=3.28	3.38	* t=3.03	

Table 9

A Comparison of TES Data for the "No-Sign" Wet Pavement Conditions Between Collection Days Shows No Significant Differences ($a \leqslant .05$)

	November 5, 1973	November 27, 1973	
NUMBER OF VEHICLES =	60.	68.	Switchpair #1 (200 feet before curve-sign location)
MEAN SPEED, MPH=	40.85	39.37	
STD. DEV. SPEED =	5.97	4.71	
MEAN INTERVEHICLE GAP, FEET	2700.26	951.74	
STD. DEV. GAP =	3168.35	1163.67	
MEAN ACCELERATION, F/S/S=	-.88	-.79	
STD. DEV. ACCELERATION =	5.55	2.62	
NUMBER OF VEHICLES =	64.	68.	Switchpair #2 (entering curvature)
MEAN SPEED, MPH=	35.86	35.07	
STD. DEV. SPEED =	6.15	4.22	
MEAN INTERVEHICLE GAP, FEET	2288.01	848.48	
STD. DEV. GAP =	2830.69	1032.54	
MEAN ACCELERATION, F/S/S=	-1.42	-1.16	
STD. DEV. ACCELERATION =	5.06	4.95	
NUMBER OF VEHICLES =	64.	67.	Switchpair #3 (tight curvature)
MEAN SPEED, MPH=	34.88	34.29	
STD. DEV. SPEED =	4.64	3.43	
MEAN INTERVEHICLE GAP, FEET	2229.69	821.66	
STD. DEV. GAP =	2746.40	1014.67	
MEAN ACCELERATION, F/S/S=	-.05	.40	
STD. DEV. ACCELERATION =	4.35	1.97	
NUMBER OF VEHICLES =	63.	66.	Switchpair #4 (leaving curve)
MEAN SPEED, MPH=	34.41	35.72	
STD. DEV. SPEED =	7.62	3.88	
MEAN INTERVEHICLE GAP, FEET	2286.10	887.00	
STD. DEV. GAP =	2787.94	1132.70	
MEAN ACCELERATION, F/S/S=	1.23	-1.66	
STD. DEV. ACCELERATION =	5.30	17.19	

The significance of mean speed reductions between pairs of experimental signing conditions at every curve location during wet pavement conditions can be seen in Figures 22 and 23. The matrices provide symbols, based on calculated t-test values, whieh indicate significant or nonsignificant speed differences for paired sign condition comparisons. Figure 22 denotes that sign conditions incorporating flashing lights elicited significantly greater speed reductions than: the "no sign" condition at the advance location, all non-flashing signs at the curve entrance, all but the "Slow When Wet" sign at the tight curvature, and the "Slippery When Wet" symbol at the curve exit. Also seen from the figure, the "Slow When Wet" panel created a significant speed reduction in the tight curvature and at the curve exit. Figure 23, four redundant matrices, illustrates significant speed reductions from the 'no sign" condition without between-signs differences at all curve locations for highest level signing. The overall effect is that the greatest impact was observed for higher level signing conditions in the tight curvature.

A noteworthy observation is the fact that one nonactivated sign ("Slow When Wet") elicited a significant speed reduction in the tight curvature. The implication arises that, when motorists have the opportunity to make an assessment of a hazard, eompliance to the appropriate remedial traffic control device is fostered. However, an analysis of specific questionnaire data for motorists who saw and properly interpreted the sign, combined with their corresponding speed data, did not bear out that assumption. A rather small proportion (about 30 percent) of the sample read the sign; because of the small sample size, statistically significant speed reductions were not evident. The "Slow When Wet" sign did not produce similar speed reductions at other sites.

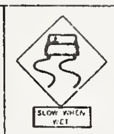
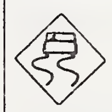
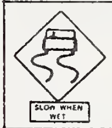
Table 10 presents the average speed differences which were observed between normative, no sign, dry pavement conditions, and experimental signing, wet pavement conditions in an examination of the sign effects relative to normal hour-to-hour speed variation at Site 1. Each cell in the table contains mean speed differences between the experimental condition and the matched timc-of-day normal driving condition. The first column in the table depicts average speed reductions resulting from the occurrence of wet pavement without signing. Conspicuity and specificity levels of experimert signing are increased as the rows are read left to right. The general trend is that greater speed differences are observed for highcr level signing. A diminished speed reductions effect is now realized for the "Slow When Wet" sign condition. Its speed differential from the normal dry condition is less than that observed for the wet pavement condition without signing. Greater speed reductions are noted for signing schemes employing flashing beacons, and some effect appears to bc elicited by thc higher specificity wording associated with those schemes.

The foregoing analysis has shown the speed-reducing effect of the signs by examining average speeds for the total driving sample. However, it must be noted that the average drivers in the population are not the target motorists to be affected by skid hazard warning signs. The fastest drivers are the most prone to skidding accidents.

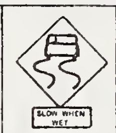
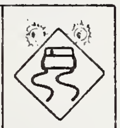
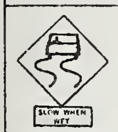
ADVANCE LOCATION

	NO SIGN			
NO SIGN	—	N	N	S
		—	N	N
			—	N
				—

ENTER CURVE

	NO SIGN			
NO SIGN	—	N	N	S
		—	N	S
			—	S
				—

TIGHT CURVE

	NO SIGN			
NO SIGN	—	N	S	S
		—	S	S
			—	N
				—

LEAVE CURVE

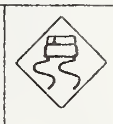
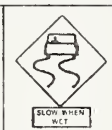
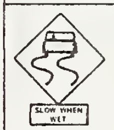
	NO SIGN			
NO SIGN	—	N	N	N
		—	S	S
			—	N
				—

Figure 22. Tables indicating significant (S) or nonsignificant (N) differences obtained between paired mean speeds for all sign conditions at each curve location. Site 1, wet pavement, November 5, 1973, ($a \leqslant .05$)

ADVANCE LOCATION

	NO SIGN	SLOW WHEN FLASHING	MAX SPEED X MPH
NO SIGN	—	S	S
SLOW WHEN FLASHING		—	N
MAX SPEED X MPH			—

ENTER CURVE

	NO SIGN	SLOW WHEN FLASHING	MAX SPEED X MPH
NO SIGN	—	S	S
SLOW WHEN FLASHING		—	N
MAX SPEED X MPH			—

TIGHT CURVE

	NO SIGN	SLOW WHEN FLASHING	MAX SPEED X MPH
NO SIGN	—	S	S
SLOW WHEN FLASHING		—	N
MAX SPEED X MPH			—

LEAVE CURVE

	NO SIGN	SLOW WHEN FLASHING	MAX SPEED X MPH
NO SIGN	—	S	S
SLOW WHEN FLASHING		—	N
MAX SPEED X MPH			—

Figure 23. Tables indicating significant (S) or nonsignificant (N) differences obtained between paired mean speeds for all signing conditions at each curve location. Site 1, wet pavement, November 27, 1973, ($a \leqslant .05$)

Table 10

Differences in Average Speeds (in mph) Between Normal No Signing, Dry Pavement and Experimental Signing, Wet Pavement Conditions at Site 1

	November 5, 1973				November 27, 1973		
	No Sign				No Sign		
200' Advance	2.3	2.7	3.1	5.7	3.4	6.7	7.1
Enter Curve	2.4	1.6	2.0	4.6	3.4	6.5	7.9
Tight Curvature	2.2	2.3	3.3	4.0	3.3	5.2	6.3
Leave Curve	3.2	2.3	3.8	4.4	3.5	5.9	6.4

The average speeds discussed above were derived for the entire sample and included those motorists who followed closely and had their speeds affected by leading vehicles. From this total population, a target sample was selected and will be used in the remainder of the analysis. A critical intervehicle gap of 200 feet, based on site geometrics and observed speeds, was used to select free flowing vehicles for which drivers determine their own speed levels. Therefore, all vehicles with lead gaps of less than 200 feet were eliminated from the sample.

The remaining vehicles were divided into four groups based on their arrival speed at the first switch pair, located 200 feet in advance of the curve. The vehicles were ranked by speed, and the highest quartile (fastest 25 percent of the drivers) were considered to be the target sample. Speeds for this group were then treated as they continued through the curve. Figure 24 depicts both average and highest quartile speed plots, making note of the critical wet pavement driving speed in the tight portion of the curve at Site 1. Plotted speeds are shown for the wet pavement, no signing condition, based on 5 November data. Corresponding time-of-day dry pavement speeds are also shown to present graphically the impact of wet pavement on each sample group. Those speeds are designated by the control period plot.

The critical wet weather driving speed, based on site roadway geometry and pavement skid resistance qualities, was calculated in the section dealing with site characterization. That speed value of 38 mph at the tight curvature is inserted in Figure 24, using the small triangle. The figure shows that the entire highest quartile driving population did exceed the critical speed during both the wet and dry pavement conditions, therefore making it evident that this quartile sample is the appropriate target population to be studied.

Using the highest quartile driving population, Figure 25 depicts mean speed effects of sign conditions tested on 5 November. To provide a frame of reference, average dry pavement speeds for the corresponding times of day are also shown. Significant reductions from the no sign, wet pavement condition are noted for two experimental sign conditions (Condition #3 – "Slow When Wet", and Condition #4 – Flashing Beacons). Speeds observed during the display of Sign Condition 2, the "Slippery When Wet" symbol used by itself, were virtually identical to those observed during the "no sign" condition; hence, no plot would be distinguishable. The figure shows that the flashing beacons did elicit a somewhat improved overall response to that of the "Slow When Wet" panel.

A similar highest quartile speed plot appears as Figure 26 depicting data collected on 27 November. Again, signs displaying flashing beacons were seen to elicit significant speed reductions from the "no sign" conditions. The moderate and high specificity signing was observed to reduce speeds to a greater extent than the low specificity signing had done on 5 November. Some benefit appears to be drived from the use of the high specificity wording ("Max Speed – 35 mph") over the moderate specificity wording ("Slow When Flashing").

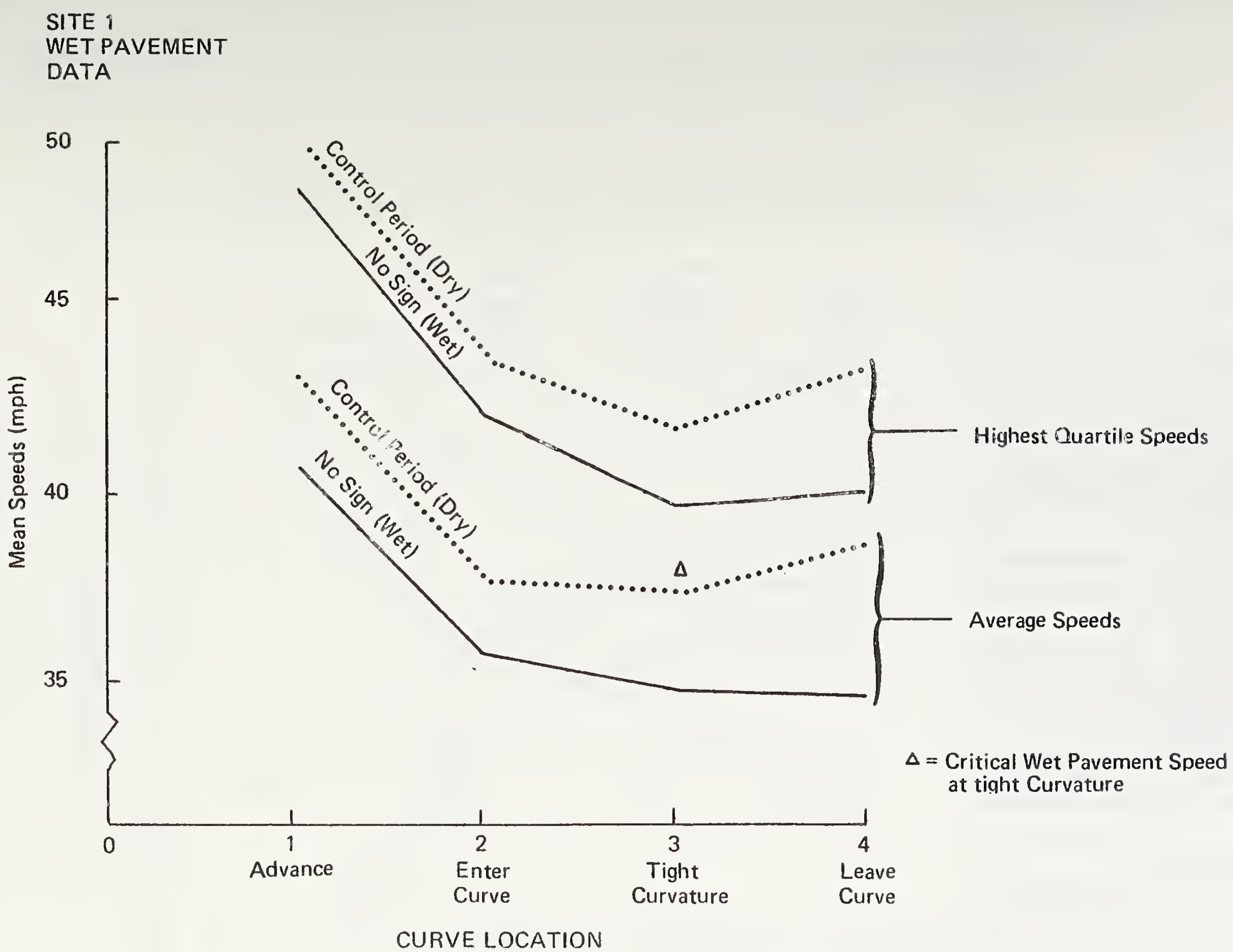


Figure 24. A graphical comparison of average and highest quartile speeds for wet and dry pavement conditions, November 5, 1973, Site 1.

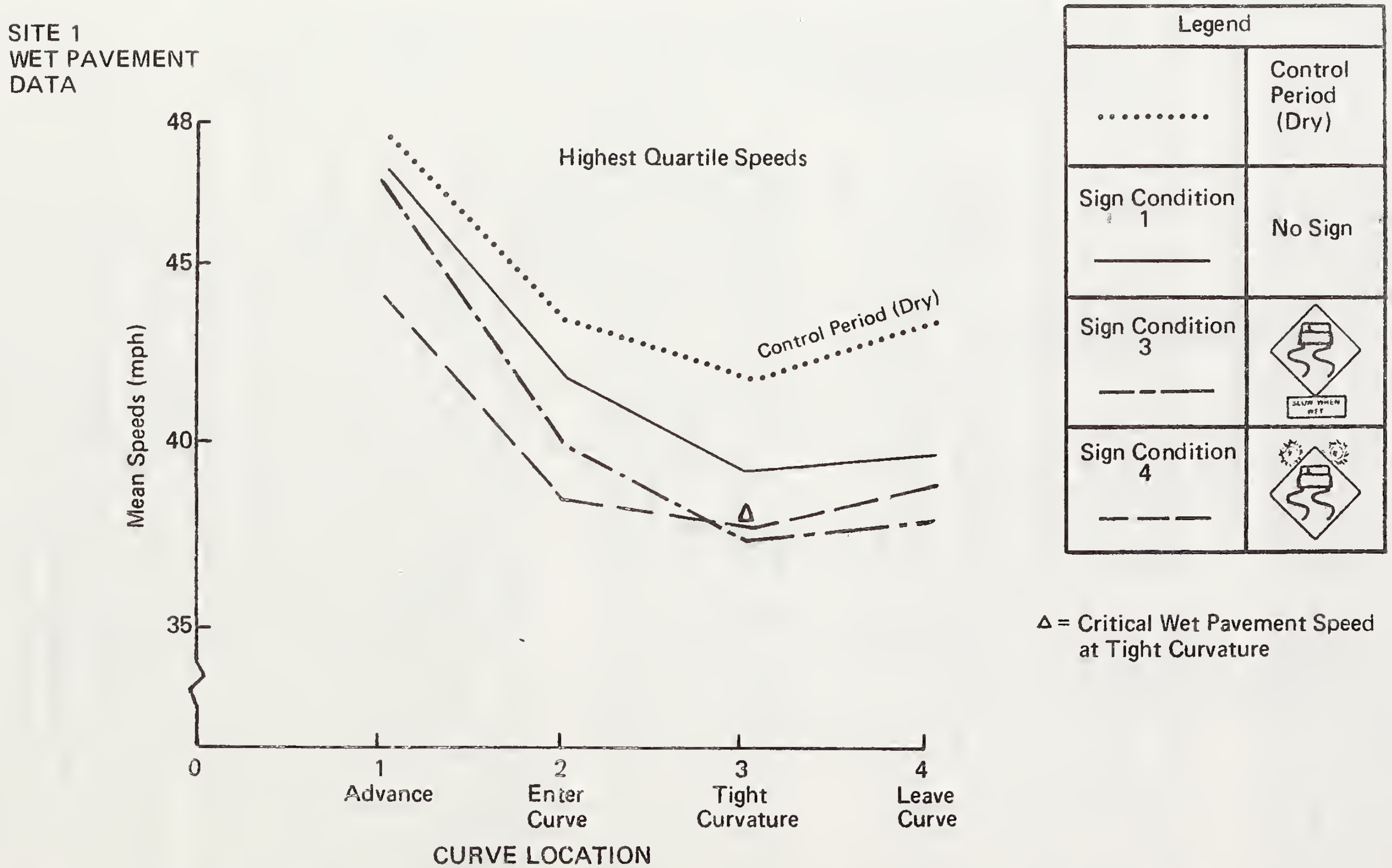


Figure 25. Mean speeds of highest quartile motorists depicting experimental signing effects during wet pavement conditions at Site 1 on November 5, 1973.

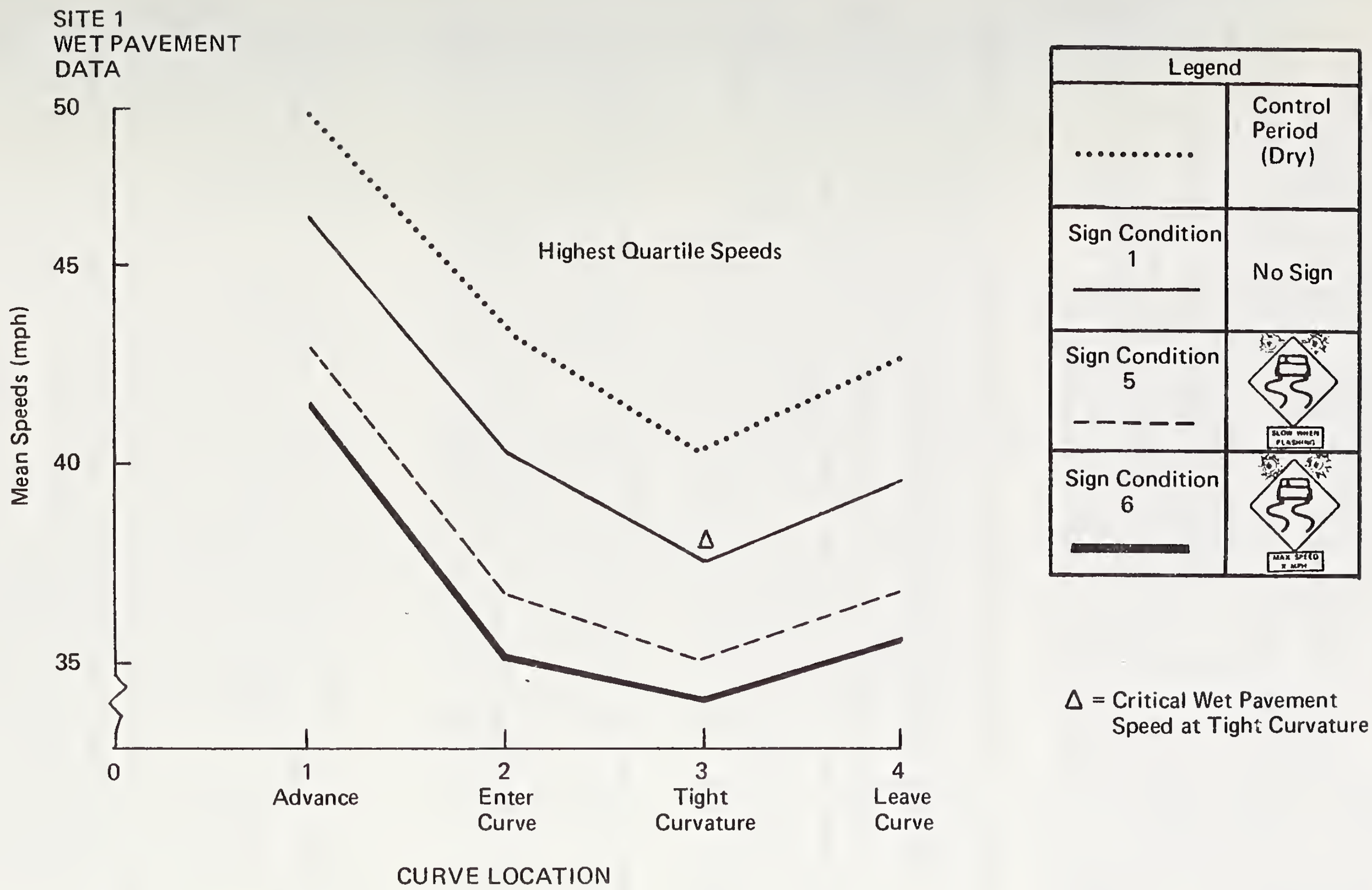


Figure 26. Mean speeds of highest quartile motorists depicting experimental signing effect during wet pavement conditions at Site 1 on November 27, 1973.

One obvious difference from data collected on 5 November is that motorists reduced speeds during the no sign condition to a level below that of the critical wet driving speed. Time-of-day speed variation accounted for the difference. To wit, it is also noted from Figure 26 that corresponding time-of-day dry pavement speeds were lower than in Figure 25. "No sign" data on 5 November were gathered during late morning hours when the motoring population was generally unfamiliar with the site. On 27 November, "no sign" condition data were gathered between 4 and 4:30 p.m. when familiar motorists were making the daily return-from-work trip. Late afternoon speeds are apparently lower at Site 1 for that reason. Questionnaire data showed that the more familiar drivers exhibited lower speeds.

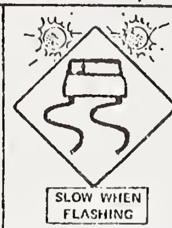
To correct for time-of-day speed variation during each signing condition, normal driving data were matched to experimental signing data on an hour-for-hour basis. Mean highest quartile speed differences obtained between normal driving and each experimental condition are indicated in Table 11. A general degradation of motorists' speed responses was noted everywhere except at the tight curvature during the period when sign condition 2 was displayed. Other signing conditions elicited improved responses with increasing levels of signing. Data in Table 11 bear out the evidence that familiar motorists on 27 November were more responsive to the wet pavement condition without signing than were those on 5 November.

A comparison of Tables 10 and 11 reveals minor differences between the average speed sample and highest quartile speed sample responses to signing. Average speed responses were more sensitive to the wet pavement condition without signing in the case where less familiar motorists appeared in the sample. Highest quartile speed responses were slightly more responsive in the tight curvature to most signing. Average speed differences between the two samples are generally similar.

It was noted in Table 9 that no significant mean speed differences existed between "no sign" data collected on 5 November and 27 November. However, Figures 25 and 26 depicted differences in behavior between the highest quartile groups in their responses to the no sign condition. An apparent explanation of this discrepancy is evident from the variable behavior of those unfamiliar motorists in the 5 November sample. Figure 27 provides mean speed plots for each quartile of both samples. The resulting families of lines illustrate less variant behavior for the familiar motorists of 27 November. The grouping is considerably tighter with a notable speed reduction for the highest quartile at the tight portion of the curvature. Speeific differences observed between the two driving samples are lower speeds at more hazardous curve locations for the highest speed percentile familiar drivers and sharper decelerations into the curve and accelerations away from the curve by the more familiar driver sample.

Table 11

Differences in Highest Quartile Speeds (in mph) Between Normal, No Signing, Dry Pavement Conditions and Experimental Signing, Wet Pavement Conditions at Site 1

	November 5, 1973				November 27, 1973		
	No Sign				No Sign		
200′ Advance	1.8	.6	1.6	4.8	2.3	5.7	7.1
Enter Curve	1.2	1.4	3.2	4.9	3.1	6.8	7.8
Tight Curvature	1.3	2.3	3.7	4.3	3.1	5.4	6.4
Leave Curve	2.7	1.9	4.6	4.5	3.0	5.9	7.1

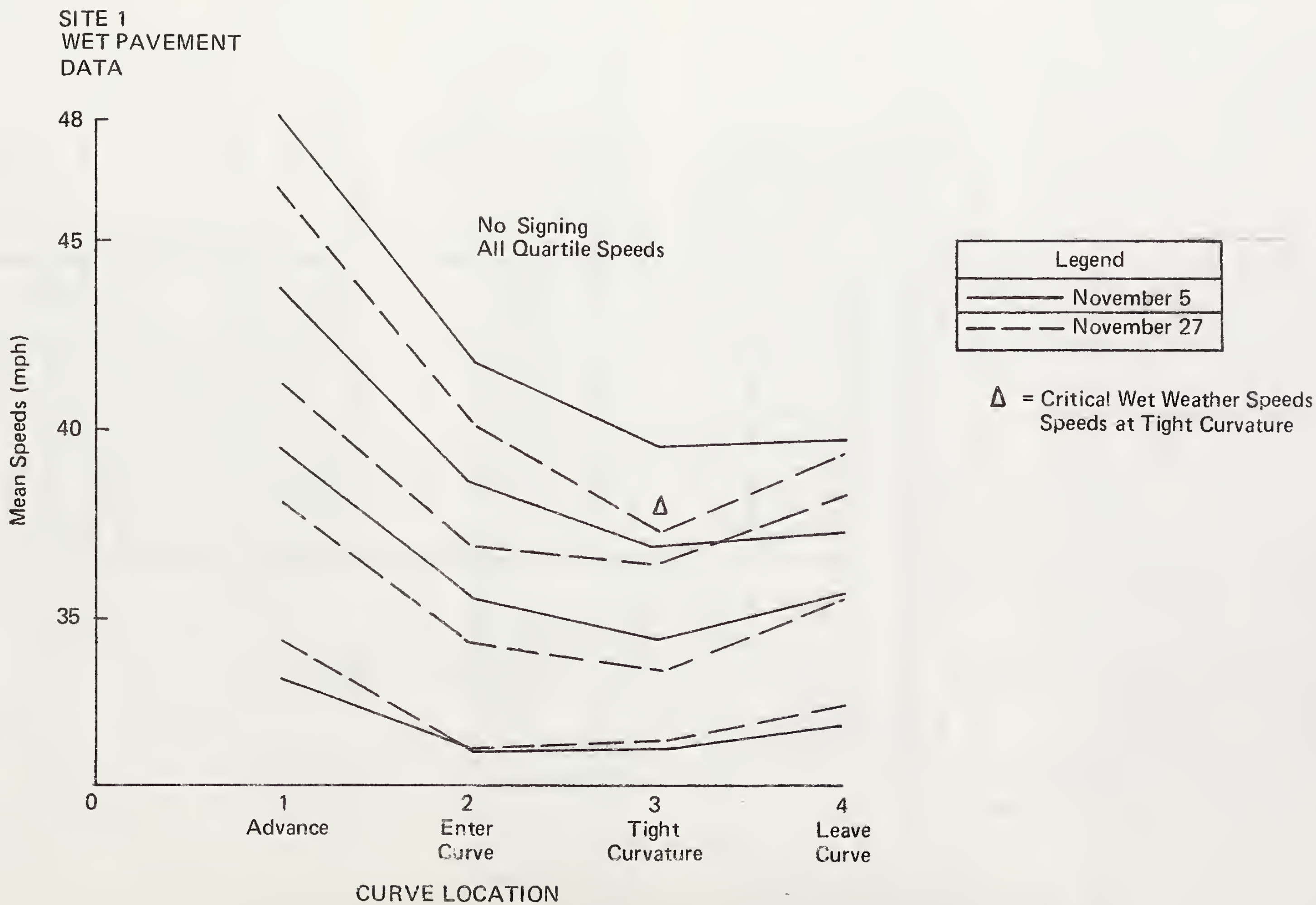


Figure 27. Mean speeds for the first through the fourth quartile motorists for different days during wet pavement, no signing conditions.

A number of findings can be cited regarding the effects of experimental signing during wet pavement conditions. Significant reductions in the mean speeds for both the total driving sample and the highest quartile sample were observed during periods when experimental signing with flashing beacons was displayed. The signing was seen to affect the speeds of motorists in all quartile groups about equally. During periods with a lower proportion of familiar motorists, the mean speed of the highest quartile was seen to exceed the critical wet driving speed when no warning signs were displayed. Warning signs which displayed flashing beacons or a "Slow When Wet" panel were effective in reducing highest quartile mean speeds below the critical level. When time-of-day speed variation corrections were applied to the data, a diminished effect of the "Slow When Wet" sign was realized. However, it was seen to elicit an effect superior to that of the symbol sign used by itself.

Acceleration and deceleration behaviors were observed to vary as a function of approach speed. Motorists who approached the curve at higher speeds exhibited greater decelerations into the curve and greater accelerations leaving the curve. This finding merely confirms speed change behavior cited in the literature (Bezorovainy, 1965). No significant effect on deceleration was observed as a function of the signing, as greater slowing was initiated further in advance of the curve in the case of activated signing. Somewhat reduced deceleration rates were observed as motorists entered the curve during periods of activated signing; however, they were not shown to be statistically significant. No reduction in acceleration rate for motorists leaving the curves was observed to be related to signing.

Attention will now be given to signing effects observed at Site 1 during dry pavement conditions. The discussion is somewhat academic in that the target skid hazard of the experimental signing occurs during wet pavement conditions.

Table 12 summarizes TES data for the wet versus dry pavement conditions without any warning signs. The motorists' natural responses to the hazard are realized through significant speed reductions due to wet pavement. A much greater reduction in the tight curvature denotes the motorists' sensitivity to the skidding hazard where it is most severe. Substantial reductions in mean spot accelerations (significant at the .10 level) are seen throughout the array. However, the most notable observation is the reduction in standard deviations indicating that motorists decelerate much less violently while negotiating a curve during wet pavement conditions.

Table 12

A Comparison of TES "No Sign" Data for Dry vs. Wet Pavement Conditions
(*Indicates significant differences: $a \leqslant .05$)

	DRY	WET		
NUMBER OF VEHICLES =	81.	68.		Switchpair #1 (200 feet before curve-sign location)
MEAN SPEED, MPH=	41.11	39.37 *		
STD. DEV. SPEED =	5.23	4.71		
MEAN INTERVEHICLE GAP, FEET	2159.65	951.74		
STD. DEV. GAP =	2259.31	1163.67		
MEAN ACCELERATION, F/S/S=	3.05	-.79		
STD. DEV. ACCELERATION =	19.60	2.62	t=2.13	
NUMBER OF VEHICLES =	79.	68.		Switchpair #2 (entering curvature)
MEAN SPEED, MPH=	36.76	35.07 *		
STD. DEV. SPEED =	5.84	4.22		
MEAN INTERVEHICLE GAP, FEET	1832.15	848.48		
STD. DEV. GAP =	1933.38	1032.54		
MEAN ACCELERATION, F/S/S=	2.35	-1.16		
STD. DEV. ACCELERATION =	18.98	4.95	t=2.03	
NUMBER OF VEHICLES =	82.	67.		Switchpair #3 (tight curvature)
MEAN SPEED, MPH=	37.10	34.29 *		
STD. DEV. SPEED =	4.08	3.43		
MEAN INTERVEHICLE GAP, FEET	1888.25	821.66		
STD. DEV. GAP =	1930.35	1014.57		
MEAN ACCELERATION, F/S/S=	3.89	.40		
STD. DEV. ACCELERATION =	17.54	1.97	t=4.57	
NUMBER OF VEHICLES =	81.	66.		Switchpair #4 (leaving curve)
MEAN SPEED, MPH=	37.97	35.72 *		
STD. DEV. SPEED =	4.66	3.88		
MEAN INTERVEHICLE GAP, FEET	1922.38	887.00		
STD. DEV. GAP =	1863.00	1132.70		
MEAN ACCELERATION, F/S/S=	4.28	-1.66		
STD. DEV. ACCELERATION =	18.37	17.19	t=3.19	

Table 13 presents dry pavement TES data summaries for all experimental signs. Significant mean speed reductions from the no sign condition are evident at virtually every curve location in the cases of moderate and high specificity wording combined with use of the flashing beacons. An hour-to-hour comparison of signing data with normative driving data revealed that no spurious effects were presented in Table 13. A brief examination of highest quartile mean speeds is provided by the plot in Figure 28. It is evident that increasingly higher levels of conspicuity and specificity do not elicit proportionately greater speed reductions during dry pavement conditions as was generally shown to be the case during wet pavement conditions. However, highest quartile motorists did exhibit significant speed reductions in response to the highest two levels of experimental signing.

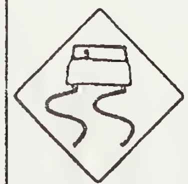
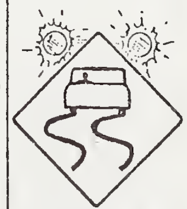
Site 2. Effects of signing were examined in view of the decelerating while cornering paradigm. Available wet pavement data were limited due to difficulties associated with the non-adherence of tapeswitches to the roadway surface during rainy periods. However, there were sufficient data to allow a comparison to be made of four signing conditions. Wet pavement TES data for sign conditions 1 through 4 are summarized in Table 14. Minor speed reductions are observed when the "Slippery When Wet" symbol is displayed; however, an unexplained degradation in responses is noted during use of the "Slow When Wet" panel. The addition of flashing beacons showed significant reductions at the .10 level in mean speeds from the "no sign" condition at both the advance and tight curvature locations.

Figure 29 depicts tables showing comparisons of paired mean speeds between signing conditions. The flashing lights are seen to significantly reduce mean speeds at both advance location and in the tight curve. They perform significantly better than the low conspicuity sign at the advance location and better than the "Slow When Wet" sign at the tight curvature. No data are available at the curve entrance point due to wet pavement tapeswitch failure.

Mean speeds for the highest quartile sample are plotted in Figure 30. Average normative highest quartile mean speeds for the dry pavement, no signing condition, are plotted for reference. It can be seen that addition of flashing beacons caused the sample to exhibit lower speeds and a slightly lower deceleration rate. This finding is identical to that obtained at Site 1. An examination of normal driving data showed no significant time-of-day variation to affect this sample, as the data were collected during a relatively short period of time.

Table 13

Summary of Data Collected December 7, 1973 Under Condition of Dry Pavement
(*Indicates significant difference from "no sign" condition: $a \leqslant .05$)

	No sign Condition # 1	 Condition # 2	 Condition # 3	 Condition # 4	 Condition # 5	 Condition # 6	
NUMBER OF VEHICLES =	81.	63.	60.	71.	86.	57.	Switchpair #1 (200 feet in advance of curve sign location)
MEAN SPEED, MPH=	41.11	41.85	41.67	42.02	39.77 *	40.16	
STD. DEV. SPEED =	5.23	4.18	7.56	5.32	4.76	6.37	
MEAN INTERVEHICLE GAP, FEET	2159.65	2087.78	2406.35	2463.09	1851.35	2365.99	
STD. DEV. GAP =	2259.31	2302.80	2579.50	2705.88	2177.45	2983.42	
MEAN ACCELERATION, F/S/S=	3.05	-.46	-5.84	-4.28	-.78	-1.26	
STD. DEV. ACCELERATION =	19.60	9.64	49.27	30.39	8.66 t=1.73	6.54	
NUMBER OF VEHICLES =	79.	66.	53.	72.	89.	59.	Switchpair #2 (entering curvature)
MEAN SPEED, MPH=	36.76	35.83	37.10	36.45	34.53*	34.59*	
STD. DEV. SPEED =	5.84	6.29	6.69	6.27	4.11	6.50	
MEAN INTERVEHICLE GAP, FEET	1832.15	1673.22	2048.89	2066.46	1571.89	1975.39	
STD. DEV. GAP =	1933.38	1836.67	2239.55	2253.15	1933.31	2602.78	
MEAN ACCELERATION, F/S/S=	2.35	-.31	.00	-3.00	-1.18	-.02	
STD. DEV. ACCELERATION =	18.98	9.30	16.92	20.48	6.45 t=2.83	6.38 t=2.03	
NUMBER OF VEHICLES =	82.	67.	59.	66.	88.	58.	Switchpair #3 (tight curvature)
MEAN SPEED, MPH=	37.10	37.38	37.42	36.78	34.51*	34.05*	
STD. DEV. SPEED =	4.08	4.34	7.12	5.31	3.51	4.62	
MEAN INTERVEHICLE GAP, FEET	1888.25	1767.12	2266.49	2236.66	1565.64	2007.52	
STD. DEV. GAP =	1930.35	1908.58	2365.67	2333.57	1910.33	2659.86	
MEAN ACCELERATION, F/S/S=	3.89	1.04	-10.66	-1.42	.91	.79	
STD. DEV. ACCELERATION =	17.54	6.91	104.87	24.51	5.91 t=4.42	5.30 t=4.04	
NUMBER OF VEHICLES =	81.	63.	60.	70.	87.	58.	Switchpair #4 (leaving curve)
MEAN SPEED, MPH=	37.97	37.45	37.13	37.86	35.75 *	34.22*	
STD. DEV. SPEED =	4.66	4.88	5.73	5.42	3.74	5.80	
MEAN INTERVEHICLE GAP, FEET	1922.38	1863.34	2135.18	2147.57	1633.77	2008.91	
STD. DEV. GAP =	1860.00	2394.78	2287.82	2327.08	2021.34	2713.55	
MEAN ACCELERATION, F/S/S=	4.28	.14	1.69	-.72	1.15	1.15	
STD. DEV. ACCELERATION =	18.07	7.36	8.33	24.32	6.23 t=3.39	6.71 t=4.08	

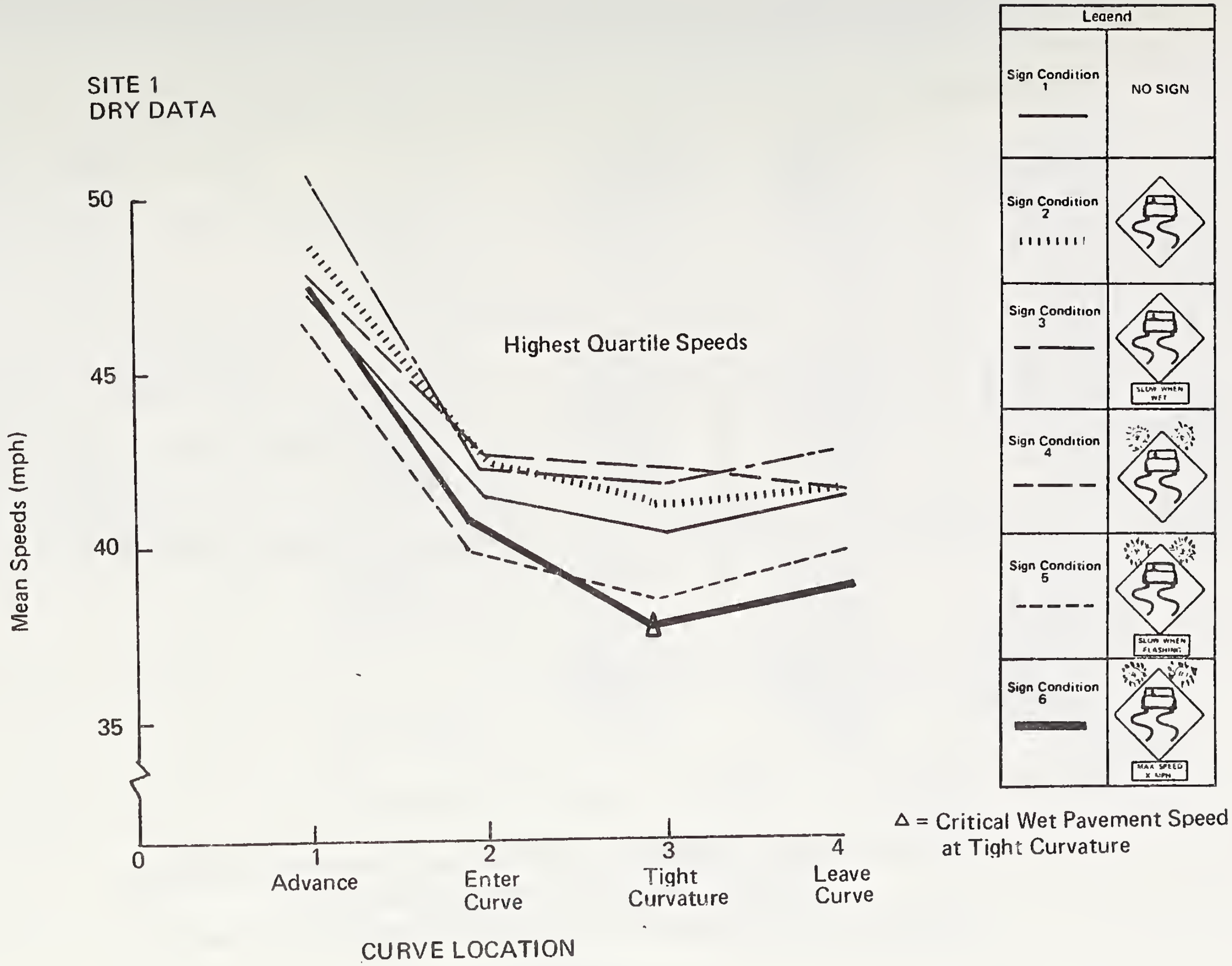


Figure 28. Mean speeds of highest quartile motorists depicting experimental signing effects during dry pavement conditions at Site 1.

Table 14

Summary of Data Collected at Site 2 During Wet Pavement Conditions for Three Experimental Signing Conditions

(*Indicates significant difference from "no signing" condition: $a \leqslant .06$)

	No sign Condition # 1	 Condition # 2	 Condition # 3	 Condition # 4		
NUMBER OF VEHICLES =	51.	64.	80.	5.	t = 1.51	150' Advance of Curve
MEAN SPEED, MPH=	39.90	38.69	40.75	36.40*		
STD. DEV. SPEED =	6.17	5.27	5.70	4.81		
MEAN INTERVEHICLE GAP, FEET	2690.63	2149.61	2550.22	2452.19		
STD. DEV. GAP =	2527.26	2444.17	2126.23	1366.63		
MEAN ACCELERATION, F/S/S=	-2.11	-1.13	-1.70	-2.74		
STD. DEV. ACCELERATION =	9.33	3.47	5.50	1.91		
NUMBER OF VEHICLES =	61.	67.	93.	5.	t = 1.59	Tight Curve
MEAN SPEED, MPH=	26.94	25.79	27.02	24.51*		
STD. DEV. SPEED =	4.44	3.90	4.32	3.17		
MEAN INTERVEHICLE GAP, FEET	1561.11	1387.40	1539.62	1718.46		
STD. DEV. GAP =	1516.25	1720.52	1355.95	874.49		
MEAN ACCELERATION, F/S/S=	.35	.63	.69	-.23		
STD. DEV. ACCELERATION =	2.01	1.24	1.54	.72		

ADVANCE LOCATION

	NO SIGN			
NO SIGN	-	N	N	N
		-	N	S
			-	S

TIGHT CURVE

	NO SIGN			
NO SIGN	-	N	N	N
		-	N	N
			-	S

Figure 29. Tables showing comparisons (S = Significant, N = Nonsignificant) of paired mean speed differences between signing conditions ($a \leqslant .05$), Site 2, wet pavement.

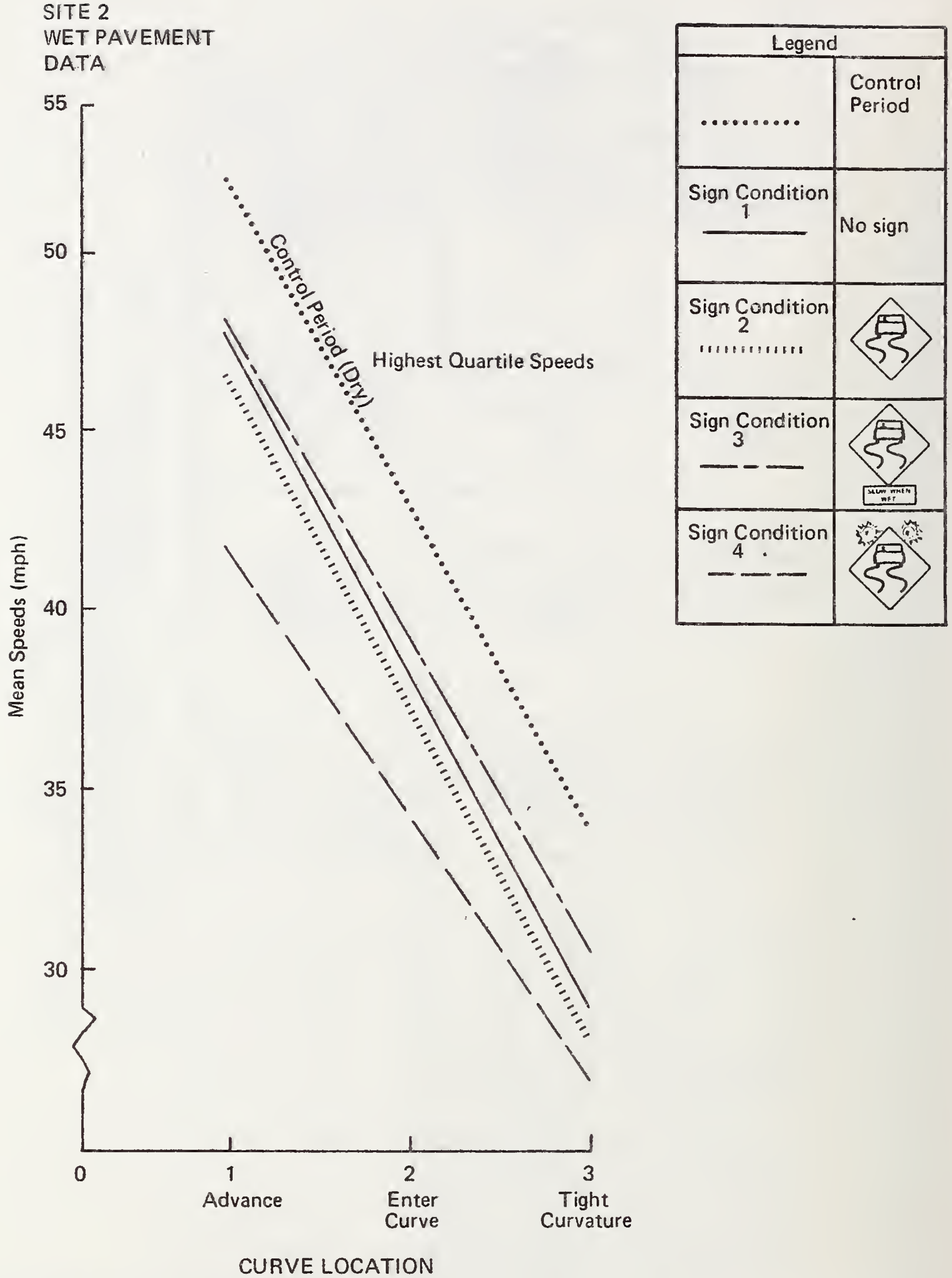


Figure 30. Mean speeds of highest quartile motorists depicting experimental signing effects during wet pavement conditions at Site 2.

TES data gathered to describe wet pavement conditions at the decelerating while cornering site served to both confirm and refute certain Site 1 findings regarding motorists' responses to experimental signing. The use of the flashing beacon was seen to significantly decrease both mean and highest quartile speeds in advance of the curve and in the tight curvature. Use of the "Slow When Wet" panel, which showed promising speed reductions at Site 1, resulted in a slight degradation of performance at Site 2.

TES data were gathered for all experimental sign conditions during dry pavement conditions at Site 2. The summary of that data is presented as Table 15. Due to the sample sizes, significant speed reductions are noted for mean differences as low as one mile per hour. These are seen to occur in the tight curve location for certain activated and non-activated sign conditions. Greater mean speed differences are noted for the activated signs supplemented with specificity wording. Their increased significance is evident from higher values obtained using the t-test. The overall dry pavement data result is the same as that obtained at Site 1 in that statistically significant speed reductions were generally realized in the cases of activated signing.

Site 3. As sign evaluative data were severely limited at the decelerating while cornering site due to wet pavement switch failures, another cornering site was observed to seek further verification of Site 1 findings. However, numerous attempts had to be aborted because of further tapeswitch problems at the second cornering site. Several attempts yielded fragmented data which will not be presented here. For instance, data were gathered in the tight curvature location only (due to switch failures at the advance location) for the nonactivated signing conditions. Observations showed a steady degradation of performance as motorists' speed increased as the pavement partially dried and temperatures increased. It was not necessary to present those data because the nonactivated signing did not produce significantly favorable results at the two sites already discussed. The fragmented data not presented only confirmed the fact that there is no strong evidence to support use of nonactivated signing.

Data will be presented to describe the wet pavement condition with the presence of all experimental signing with one exception. Because of the unpredictable nature of rainfall, it was not possible to test all of the signing on any single given day. Therefore, the most productive attempt is described. Unfortunately, the data presented here are limited to the curve approach, its entry point, and the tight curvature. Although these are the critical target positions in a curve, it is regretful that switch failures precluded gathering acceleration data as motorists exited the curve.

Table 15

Summary of Data Collected at Site 2 During Dry Pavement Conditions
for all Experimental Signing
(*Indicates significant difference from "no sign" condition: $a \leqslant .05$)

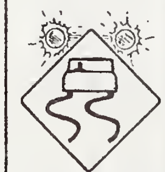
	No sign Condition # 1	 Condition # 2	 Condition # 3	 Condition # 4	 Condition # 5	 Condition # 6	
NUMBER OF VEHICLES =	57.	71.	77.	99.	67.	106.	Advance
MEAN SPEED, MPH=	47.14	46.23	46.31	47.22	45.91	46.04	
STD. DEV. SPEED =	5.20	4.88	6.24	5.21	4.81	4.81	
MEAN INTERVEHICLE GAP, FEET	3326.36	2820.87	2548.74	2052.51	2885.29	820.98	
STD. DEV. GAP =	3181.38	3021.38	2455.55	2403.08	3489.51	905.69	
MEAN ACCELERATION, F/S/S=	-1.61	-2.03	-2.37	-1.56	-.80	-1.64	
STD. DEV. ACCELERATION =	3.71	3.88	3.77	4.08	3.55	3.48	
NUMBER OF VEHICLES =	73.	86.	97.	129.	87.	124.	Enter Curve
MEAN SPEED, MPH=	35.46	34.58	34.87	35.43	34.28*	34.14*	
STD. DEV. SPEED =	3.85	4.40	3.93	3.68	4.45	4.11	
MEAN INTERVEHICLE GAP, FEET	1780.48	1750.26	1578.00	1204.86	1750.61	1189.37	
STD. DEV. GAP =	1704.78	1778.45	1565.10	1147.12	2045.70	1279.71	
MEAN ACCELERATION, F/S/S=	-4.32	-3.06	-3.55	-3.74	-3.39	-2.94	
STD. DEV. ACCELERATION =	2.56	2.08	3.22	2.63	2.37	2.40	
					t = 1.82	t = 2.31	
NUMBER OF VEHICLES =	77.	88.	97.	128.	86.	123.	Tight Curvature
MEAN SPEED, MPH=	31.35	30.34*	30.42*	30.91	30.13*	30.14*	
STD. DEV. SPEED =	3.16	3.99	3.75	3.03	3.93	4.25	
MEAN INTERVEHICLE GAP, FEET	1585.71	1499.13	1377.46	1028.83	1559.76	1027.38	
STD. DEV. GAP =	1483.11	1475.82	1418.65	956.19	1814.92	1061.67	
MEAN ACCELERATION, F/S/S=	2.59	1.73	1.39	2.18	2.15	4.24	
STD. DEV. ACCELERATION =	2.92	4.11	3.22	3.21	3.22	28.14	
		t = 1.82	t = 1.77		t = 2.30	t = 2.31	

Table 16 is a summary of TES data gathered on 29 March 1974. Slight but insignificant speed reductions are noted at the advance and curve entry locations during the period at which sign #2 was displayed. However, an increase in tight curve speeds during that period implies no increased motorist concern for a potential skidding hazard. Speed decreases throughout the curve are observed for the remainder of the signs displayed. Duc to the large sample size, statistically significant reductions are readily evident, and are, in fact, somewhat misleading as small speed reductions would have a negligible affect on motorists' stopping distances. However, they are indicated in the table solely to demonstrate differential effects between signing conditions.

A correction for time-of-day speed variation, presented in Table 17, lists reductions in mean speeds between normal driving and experimental conditions. It is noted from the table that motorists exhibited no slowing for either the wet pavement or the lowcst level sign at the advance location. As Site 3 is a low speed site, the absence of motorists' slowing at curves in response to wet pavements is consistent with findings in the literature (Glennon, 1971). The use of nonactivated signing produced speed reductions from normal conditions of less than one mile per hour. The use of activated signing produced improved responses, and the addition of higher specificity wording produeed markedly improved responses. This finding of improved differential responses with highly conspicuous signs is consistent with observations at Sites 1 and 2.

Table 18 summarizes TES speed data for the highest quartilc sample. This group cxhibited significantly lower speeds in response to high conspicuity signing supplemented with moderate specificity wording. The low specificity and conspicuity sign is also seen to affect the high quartile sample. This latter observation is suspect, however, in view of normally lower time-of-day speeds that were evident from the total population comparison presented in Table 17.

Table 19 summarizes dry pavement data for all experimental signing at Site 3. As observed at other sites, greater speed reductions were realized for higher level signing conditions.

Overview of Sign Evaluation

Generally consistent effects of experimental signing to warn of potential skidding hazards were observed at the three sites. With one exception, there was no evidence to support the use of low conspicuity signing. At Site 1, the use of low conspicuity, moderate specificity signing ("Slow When Wet") elicited significantly reduced motorists' speeds at the curve entry point and in the tight curvature during wet pavement conditions. However, this observation was not repeated at either Site 2 or 3.

Table 16
Summary of Data Collected at Site 3 During Wet Pavement Conditions
for Four Experimental Signing Conditions
(*Indicates significant reduction from "no sign" condition: $a \leqslant .05$)

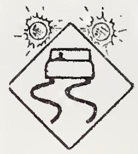
	 Condition # 2	 Condition # 5	 Condition # 6	 Condition # 4	No sign Condition # 1		
NUMBER OF VEHICLES =	231.	322.	202.	355.	376.	150′ Advance of Curve	Decelerating
MEAN SPEED, MPH=	32.12	28.99*	29.04*	30.37*	31.81		
STD. DEV. SPEED =	4.05	5.08	4.32	4.05	3.99		
MEAN INTERVEHICLE GAP, FEET	503.08	447.26	693.15	453.61	432.40		
STD. DEV. GAP =	565.18	530.41	885.34	602.19	555.60		
MEAN ACCELERATION, F/S/S=	-.33	-.58	-.63	-.47	-.03		
STD. DEV. ACCELERATION =	2.13	1.92	2.05	2.14	2.12		
NUMBER OF VEHICLES =	235.	328.	206.	359.	383.	Enter Curve	
MEAN SPEED, MPH=	22.19	21.10*	21.08*	21.81*	22.38		
STD. DEV. SPEED =	2.68	2.52	2.69	2.45	2.61		
MEAN INTERVEHICLE GAP, FEET	340.05	319.33	481.03	320.23	293.61		
STD. DEV. GAP =	391.44	396.67	622.08	434.60	386.99		
MEAN ACCELERATION, F/S/S=	-3.19	-2.13	-2.08	-2.68	-2.72		
STD. DEV. ACCELERATION =	3.18	1.66	1.78	1.87	1.92		
NUMBER OF VEHICLES =	236.	311.	207.	357.	381.	Tight Curvature	Cornering
MEAN SPEED, MPH=	19.09*	18.52*	18.57*	19.00*	19.47		
STD. DEV. SPEED =	2.30	2.27	2.46	2.34	2.43		
MEAN INTERVEHICLE GAP, FEET	292.67	283.55	414.72	273.17	255.81		
STD. DEV. GAP =	343.91	355.73	537.04	377.96	340.16		
MEAN ACCELERATION, F/S/S=	.41	.60	.57	.49	.22		
STD. DEV. ACCELERATION =	2.50	2.60	3.00	2.69	3.22		
NUMBER OF VEHICLES =	117.	No Data Due to Switch Failure				Leave Curve	Accelerating
MEAN SPEED, MPH=	19.96						
STD. DEV. SPEED =	2.03						
MEAN INTERVEHICLE GAP, FEET	344.82						
STD. DEV. GAP =	398.17						
MEAN ACCELERATION, F/S/S=	2.17						
STD. DEV. ACCELERATION =	2.07						
NUMBER OF VEHICLES =	238.	327.	209.	359.	382.	150′ Beyond Curve	
MEAN SPEED, MPH=	25.61	25.06*	25.45*	25.74	26.02		
STD. DEV. SPEED =	3.11	3.18	3.12	3.15	3.23		
MEAN INTERVEHICLE GAP, FEET	389.31	372.55	576.31	370.03	341.78		
STD. DEV. GAP =	450.40	460.80	745.54	471.98	454.29		
MEAN ACCELERATION, F/S/S=	1.34	1.19	1.53	1.32	1.32		
STD. DEV. ACCELERATION =	1.50	1.44	1.56	1.54	1.61		

Table 17

Differences in Average Speeds Between Normal No Signing, Dry Pavement and Experimental Signing, Wet Pavement Conditions at Site 3

	No Sign				
Advance	–.1	–.4	1.9	3.2	3.2
Enter Curve	.4	.4	1.0	2.1	1.9
Tight Curve	.5	.8	1.0	1.7	1.3

Table 18

Selected Population Parameters (n, mean speed, std. dev) for Highest Quartile Motorists, Wet Pavement Conditions, Site 3
(*Indicates significant reduction from "no sign" condition: $a \leqslant .05$)

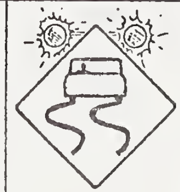
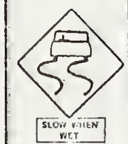
	No Sign				
Advance	68 37.50 2.18	46 37.40 1.88	61 36.76* 2.02	58 35.58* 2.77	36 35.06* 2.72
Enter Curve	60 25.12 2.07	40 24.72 1.61	51 24.70 1.83	48 23.80* 1.90	29 23.75* 2.25
Tight Curve	54 21.60 2.32	34 20.87 1.99	46 21.11 1.96	41 20.50 2.07	26 20.86 1.74

Table 19

Summary of Data Collected at Site 3 During Dry Pavement Conditions for All Experimental Signing Conditions

(*Indicates significant reduction from "no sign" condition: $\alpha \leq .05$)

	No sign Condition # 1	 Condition # 2	 SLOW WHEN WET Condition # 3	 Condition # 4	 SLOW WHEN FLASHING Condition # 5	 MAX SPEED X MPH Condition # 6		
NUMBER OF VEHICLES =	201.	179.	175.	478.	242.	230.	150' Advance of Curve	Decelerating
MEAN SPEED, MPH=	32.30	31.71	32.27	29.46*	30.43*	30.54*		
STD. DEV. SPEED =	3.33	5.07	4.63	4.76	5.49	4.85		
MEAN INTERVEHICLE GAP, FEET	404.59	707.75	739.98	380.23	501.32	510.72		
STD. DEV. GAP =	513.59	876.07	870.17	530.43	602.98	579.00		
MEAN ACCELERATION, F/S/S=	-.09	-.26	-.44	-.14	-.61	-.30		
STD. DEV. ACCELERATION =	1.79	3.15	1.89	1.94	1.81	2.16		
NUMBER OF VEHICLES =	198.	183.	175.	484.	246.	232.	Enter Curve	
MEAN SPEED, MPH=	22.47	21.53*	22.31*	21.01*	21.71*	21.31*		
STD. DEV. SPEED =	2.14	2.98	2.60	2.74	2.78	2.81		
MEAN INTERVEHICLE GAP, FEET	279.66	409.77	502.19	260.35	340.88	357.50		
STD. DEV. GAP =	353.68	530.58	577.78	354.06	408.47	421.16		
MEAN ACCELERATION, F/S/S=	-2.71	-2.38	-2.82	-2.22	-2.20	-2.52		
STD. DEV. ACCELERATION =	1.84	2.16	1.82	1.77	1.81	1.87		
NUMBER OF VEHICLES =	190.	176.	176.	456.	241.	225.	Tight Curvature	Cornering
MEAN SPEED, MPH=	19.75	19.11*	19.55	18.74*	19.14*	18.74*		
STD. DEV. SPEED =	2.03	2.58	2.42	2.38	2.31	2.39		
MEAN INTERVEHICLE GAP, FEET	260.46	432.78	433.14	238.72	305.04	319.71		
STD. DEV. GAP =	331.53	489.38	493.12	313.67	367.04	377.40		
MEAN ACCELERATION, F/S/S=	.74	.44	-.02	.57	.56	.42		
STD. DEV. ACCELERATION =	2.59	2.89	2.79	2.56	2.41	3.06		
NUMBER OF VEHICLES =	194.	179.	176.	459.	240.	229.	Leave Curve	Accelerating
MEAN SPEED, MPH=	20.45	20.09	20.34	19.54*	20.03*	19.51*		
STD. DEV. SPEED =	1.98	2.54	2.39	2.43	2.31	2.21		
MEAN INTERVEHICLE GAP, FEET	267.88	443.27	438.84	251.35	322.95	330.42		
STD. DEV. GAP =	342.48	496.87	482.06	328.22	383.65	396.46		
MEAN ACCELERATION, F/S/S=	2.23	2.03	1.66	1.88	1.83	1.92		
STD. DEV. ACCELERATION =	1.74	1.64	2.02	1.63	1.97	1.59		
NUMBER OF VEHICLES =	203.	189.	175.	475.	253.	236.	150' Beyond Curve	
MEAN SPEED, MPH=	25.87	25.43	25.69	24.21*	24.60*	24.56*		
STD. DEV. SPEED =	2.99	3.71	3.16	3.60	3.51	3.67		
MEAN INTERVEHICLE GAP, FEET	326.16	536.12	575.70	304.47	381.71	407.21		
STD. DEV. GAP =	416.12	606.93	655.61	406.36	460.85	495.51		
MEAN ACCELERATION, F/S/S=	1.22	1.17	1.08	.81	.85	.95		
STD. DEV. ACCELERATION =	1.58	1.44	1.52	1.74	1.53	1.42		

Sufficient site characterization data at Site 1 permitted a comparison of observed motorists' speeds with the critical wet pavement speed based on the site geometry and pavement characteristics. All high conspicuity experimental signing did result in virtually all motorists driving below that speed during wet pavement conditions. Substantial speed reductions obtained at the remaining sites with high conspicuity signing displayed during wet pavement conditions did corroborate that the flashing beacons were effective in warning motorists of the potential hazard.

The foregoing is based on mean speeds for both the total driving sample and the highest quartile speed group. No significant changes in deceleration behavior could be attributed to the signing, as speed reductions due to flashing signs were initiated sufficiently in advance of the test curves.

Special Study: Effects of Increased Conspicuity

On the evening of 11 March 1974, a special study was conducted at Site 3 to examine the effects, on wet pavement driving, of high conspicuity signing used during hours of darkness. The sign's flashing beacons were comprised of 100-watt bulbs behind amber diffusing lenses; they created a bright but not blinding light. Highly reflective sign face sheeting appeared brighter to the motorist than did the beacons. The purpose of the study was to examine the impact on motorists of the increased conspicuity of the signing during hours of darkness as opposed to daytime usage discussed earlier.

Data collection commenced at 7:30 p.m. and continued to 10:30 p.m. Light rain fell during the entire period; however, mixed snow flurries did impact on observed speeds during one hour of data collection. Table 20 presents a summary of TES data for this special study. Significant speed reductions were observed at the advance location during hours when the high conspicuity signing was used. However, reductions for the remainder of the curvature are significant only during the hours when sign condition 5 was displayed and their observation coincided with the onset of snow flurries mixed with the rain. Therefore, the drop in mean speeds is not attributed to the signing.

A more detailed look at motorists' responses is obtained by examination of the highest quartile samples as they are presented in Table 21. The impact on this select population is similar to that obtained with the total sample, in that significantly reduced speeds result at the advance location with a general degradation of performance throughout the curve. A comparison of the table with Table 18, presenting highest quartile speeds during daylight conditions, reveals a similar effect. A one-half mile per hour greater difference between no signing and highest level signing is observed for the nighttime condition; however, performance within the curve is not favorable. Therefore, no evidence is provided to indicate that the high conspicuity signing was more effective due to its increased conspicuity during darker conditions.

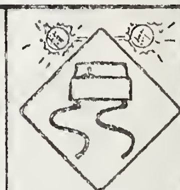
Table 20

Summary of Data Collected During Special Study of Increased Conspicuity Resulting from Flashing Beacon Use During Hours of Darkness and Wet Pavement Conditions
(*Indicates significant reduction from "no sign" condition: $a \leqslant .05$)

	No sign Condition # 1	 Condition # 4	 Condition # 5	 Condition # 6		
NUMBER OF VEHICLES =	44.	105.	103.	131.	150' Advance of Curve	Decelerating
MEAN SPEED, MPH=	32.77	29.18*	27.13*	29.12*		
STD. DEV. SPEED =	3.78	4.19	4.87	4.18		
MEAN INTERVEHICLE GAP, FEET	1618.41	1093.32	1155.58	659.08		
STD. DEV. GAP =	2205.99	1249.60	1269.64	845.20		
MEAN ACCELERATION, F/S/S=	-.25	.39	-.09	-.07		
STD. DEV. ACCELERATION =	2.44	4.51	1.43	2.04		
NUMBER OF VEHICLES =	50.	101.	104.	130.	Enter Curve	
MEAN SPEED, MPH=	20.46	20.58	19.60*	20.70		
STD. DEV. SPEED =	2.58	2.86	2.90	2.50		
MEAN INTERVEHICLE GAP, FEET	896.17	797.03	817.79	481.31		
STD. DEV. GAP =	1271.86	931.30	916.79	642.93		
MEAN ACCELERATION, F/S/S=	-2.22	-2.00	-1.83	-1.74		
STD. DEV. ACCELERATION =	1.59	1.67	1.55	1.45		
NUMBER OF VEHICLES =	49.	95.	99.	123.	Tight Curvature	Cornering
MEAN SPEED, MPH=	18.14	18.26	17.40*	18.49		
STD. DEV. SPEED =	2.71	2.82	2.71	2.31		
MEAN INTERVEHICLE GAP, FEET	800.16	683.59	748.75	443.68		
STD. DEV. GAP =	1112.03	778.58	839.14	603.17		
MEAN ACCELERATION, F/S/S=	.67	.45	.67	.45		
STD. DEV. ACCELERATION =	1.56	2.35	1.85	2.22		

Table 21

Selected Population Parameters (n, mean speed, standard deviation) for Highest Quartile Motorists, Wet Pavement, Increased Conspicuity Signing at Site 3
(*Indicates significant reduction from "no sign" condition: $a \leqslant .05$)

	No Sign		 	
Advance	11 37.92 2.06	24 34.91* 2.82	20 34.22* 2.79	28 34.99* 3.19
Enter Curve	10 22.21 2.14	22 22.17 1.98	20 22.77 2.16	26 22.90 2.61
Tight Curvature	10 19.42 2.28	20 22.17 2.45	19 20.00 1.98	24 20.43 2.64

It should be emphasized that motorists' slowing in the curve at Site 3, as a response to a skid hazard, was not necessarily expected since low speeds were normally observed. The effectiveness of signs to warn of skid hazard at Site 3 is based primarily on the approach speed. Therefore, the ability of highly conspicuous signing to act as a warning during hours of darkness was seen to be compatible with daytime observations, based on motorists' responses at the advance location.

Ministudies: Driver Responses to Rainfall Onset

The effect on pavement skid resistance of the onset of rainfall is a major concern. Therefore, it follows that motorists' responses to the pavement's transition from the dry to wet condition should be documented. As a primary objective of this research is to assess motorists' responses to varying degrees of skid hazard as a function of the experimental signing, a series of ministudies was undertaken to examine speed changes for the short period during which the pavement undergoes changes through the dry, wetting, and wet conditions. Due to the unpredictable nature of rainfall occurrence and the preparation necessary to collect data, it was not possible to examine the rainfall onset phenomenon for all experimental signing. Therefore, ministudies were conducted for conditions of no signing, low, and high specificity and conspicuity signs. The "no signing" ministudy will be discussed first in detail; differences observed for the latter two sign conditions will then be described.

Response without Signing. On 28 January, when rain-shower activity throughout the day was predicted, a ministudy was conducted at one cornering site (Site 3) to examine motorists' responses to the transition from dry to wet pavement conditions. Fortunately, rainfall occurrence on that day was most conducive to such a study. Shortly following deployment of the TES, a heavy drizzle occurred which thoroughly wetted the pavement. This was followed by a 4½-hour period of no precipitation, allowing for complete drying of the pavement. A heavy rainfall of short duration then followed (.05 inches in 16 minutes). Hence, comparative speed data were obtained for dry, wetting, and wet (light rain, heavy rain, drying) pavement conditions.

For purposes of the ministudies, pavement conditions are defined as follows:

Dry	–	pavement appears completely dry over entire surface.
Wetting	–	rainfall has started; no measurable precipitation. Condition begins as first windshield wiper usage is observed, and ends when virtually all vehicles exhibit wiper usage.

Wet (light rain) – pavement is very wet in appearance and virtually all motorists are using wipers. Precipitation rate is not measurable.

Wet (heavy rain) – same as above, but precipitation rate is measurable.

Wet (drying) – rainfall has completely subsided, but heavy water film remains on pavement.

Admittedly, more sophisticated definitions of pavement conditions which incorporate quantitative measurements of skid resistance would be desirable; however, the decelerometer did not prove sufficiently sensitive to differentiate between conditions observed in the mini-study.

Table 22 provides summaries of data collected for each of the pavement conditions defined above. Dry pavement data periods were defined as the 20 minutes immediately preceding the beginning of rainfall in order to eliminate the confounding effect of normative hour-to-hour speed variation. Significant differences (at the .05 level) in mean speeds and accelerations from the dry conditions for each wetness condition are indicated in the table. Differences observed during pavement wetting conditions are similar for both heavy and light rainfalls, as light drizzles preceded each rainfall for about 15 minutes. However, the wet pavement condition produced considerably greater changes in the case of heavy rainfall. Most notable are the reduced speeds as motorists enter the curve and continue through the tight curvature. The increased mean acceleration observed as motorists leave the curve in heavy rain is a logical result of lower tight curve speed.

In order to account for the effect of actual precipitation and its inherent side effects such as reduced visibility, the table provides data for a short period of drying which immediately followed the heavy rainfall. Similar mean speed and acceleration values obtained suggest that drivers were sensitive to the possible friction reduction which resulted from presence of pavement water film. The comparison is interesting between this drying condition, characterized by heavy water film, and the wet condition during light rain when the pavement was also thoroughly wetted but to a lesser degree. Mean speeds are lower throughout the decelerating and cornering portions of the curve with the presence of the greater water film.

Table 22

Summary of Data Collected During Ministudy to Examine the Effects of Rainfall on Motorist's Behavior

(*Indicates significant difference from the dry condition: $a \leqslant .05$)

	LIGHT RAINFALL			HEAVY RAINFALL					
	DRY	WETTING	WET	DRY	WETTING	WET	DRYING		
NUMBER OF VEHICLES =	157.	115.	163.	210.	121.	133.	125.	150' advance of curve	DECELERATING
MEAN SPEED, MPH=	33.33	32.33*↓	31.39*↓	32.06	31.62	30.92*↓	30.95*↓		
STD. DEV. SPEED =	4.45	4.29	3.57	4.44	3.08	3.42	4.17		
MEAN INTERVEHICLE GAP, FEET	562.31	505.78	421.44	405.55	465.17	421.88	453.07		
STD. DEV. GAP =	605.53	608.35	551.84	517.71	512.20	547.75	535.40		
MEAN ACCELERATION, F/S/S=	.55	-.06	.26	.01	.03	-.06	.02		
STD. DEV. ACCELERATION =	11.12	1.94	5.91	2.58	1.89	2.16	1.72		
NUMBER OF VEHICLES =	159.	114.	164.	210.	125.	131.	125.	Enter curve	
MEAN SPEED, MPH=	22.48	22.58	22.43	22.86	22.52	21.45*↓	21.84*↓		
STD. DEV. SPEED =	2.63	2.53	2.15	2.41	2.04	2.59	2.76		
MEAN INTERVEHICLE GAP, FEET	375.90	366.78	295.63	291.00	321.33	299.55	322.35		
STD. DEV. GAP =	422.13	469.70	408.34	378.72	374.50	404.90	393.30		
MEAN ACCELERATION, F/S/S=	-2.61	-3.02	-2.92	-2.62	-2.53	-2.57	-2.61		
STD. DEV. ACCELERATION =	2.71	1.88	1.79	1.96	1.76	1.58	1.92		
NUMBER OF VEHICLES =	159.	115.	162.	207.	124.	127.	121.	Tight curvature	CORNERING
MEAN SPEED, MPH=	19.31	19.10	19.13	19.88	19.53	18.71*↓	18.97*↓		
STD. DEV. SPEED =	2.31	2.14	2.00	2.20	1.99	2.17	2.51		
MEAN INTERVEHICLE GAP, FEET	320.95	311.17	255.56	251.79	283.40	263.37	279.01		
STD. DEV. GAP =	366.93	405.65	357.05	332.98	339.02	366.02	350.44		
MEAN ACCELERATION, F/S/S=	.55	.21	.34	.19	-.24*↓	.50	.36		
STD. DEV. ACCELERATION =	3.39	2.17	1.78	1.95	1.60	2.31	1.64		
NUMBER OF VEHICLES =	158.	114.	164.	208.	124.	132.	120.	Leave curve	ACCELERATING
MEAN SPEED, MPH=	19.77	19.53	19.24*↓	20.17	20.01	19.12*↓	19.61*↓		
STD. DEV. SPEED =	2.25	1.97	2.17	2.27	1.92	2.04	2.29		
MEAN INTERVEHICLE GAP, FEET	330.95	318.49	253.77	256.61	289.50	263.56	294.11		
STD. DEV. GAP =	376.36	407.74	356.74	336.14	347.37	366.77	357.29		
MEAN ACCELERATION, F/S/S=	2.35	2.31	2.17	2.09	2.37	2.69*↑	2.40		
STD. DEV. ACCELERATION =	3.26	1.92	2.75	3.90	1.87	1.65	2.17		
NUMBER OF VEHICLES =	160.	114.	168.	208.	125.	130.	122.	150' beyond curve	
MEAN SPEED, MPH=	25.97	26.07	25.32*↓	25.97	25.71	25.31*↓	25.97		
STD. DEV. SPEED =	3.17	2.68	2.92	3.06	2.63	2.80	2.71		
MEAN INTERVEHICLE GAP, FEET	431.03	420.50	319.66	328.78	362.56	352.70	381.73		
STD. DEV. GAP =	473.07	531.17	415.63	428.32	415.72	471.66	449.23		
MEAN ACCELERATION, F/S/S=	1.93	1.30	1.28	1.41	1.12	.99	1.35		
STD. DEV. ACCELERATION =	6.71	1.76	1.69	3.65	1.78	1.92	1.68		

A more detailed explanation of how the driving sample reacted to all degrees of pavement wetness is illustrated in Figure 31. Mean speeds are plotted for both the highest and lowest quartile groups to provide some insight regarding driver variability of responses. Pavement conditions shown are dry, wetting, and wet, both during the occurrence of rainfall and following its termination. The most notable impact of the wetting condition indicated by the shaded area is the reduced speed variation throughout the curvature. However, the magnitude of speed is more greatly affected by the continued presence of rather than by the occurence of pavement wetness. That is, speeds are shown to decrease for each ensuing condition of wetness rather than to decrease abruptly as the pavement becomes wet. This effect is most noticeable in the critical tight curvature. The wetting condition is seen to sharply reduce motorists' speeds as they leave the curvature. This is not the critical skidding accident prone time. Table 22 further indicates that slowing continues there as the pavement becomes wetter.

The data, therefore, strongly suggest that motorists are more aware of a potential skid hazard during heavy rather than light rainfall. Furthermore, little evidence is available here to substantiate the popular belief that motorists are responsive to some perceived peak slipperiness which is said to occur immediately at the onset of rainfall. It is appropriate to note that peak slipperiness associated with rainfall onset has never been documented (NCHRP, 1972).

Response with Low Level Signing. On 29 March 1974, low specificity and conspicuity signing was displayed at the onset of a substantial rainfall lasting for hours. Table 23 summarizes TES data collected for the ministudy which utilized the identical procedures and pavement condition definitions described above. On this day, the wetting condition existed for only 5 minutes as the period of prerainfall drizzle was much shorter than that previously cited. The table indicates an increase in mean speeds during the pavement wetting period and a nonsignificant speed reduction at the advance location. Nonsignificant reductions caused by pavement wetting are noted throughout the remainder of the curvature. Further, minor speed reductions are noted for the wet pavement condition as the rainfall continued. Thus, motorists are seen to be generally less sensitive to potential slipperiness than in the previous ministudy. Certainly, it is obvious that the low level sign exhibited no favorable impact on motorists' response to pavement wetting.

Response with High Level Signing. High conspicuity and specificity signing ("Max Speed 15 MPH" and flashing beacons) was displayed during rainfall onset which occurred 11 March 1974. A 15-minute period of pavement wetting preceded sustained rainfall. Although the period was short, 70 vehicles passed the site, providing an adequate study sample.

SITE 3
MINISTUDY

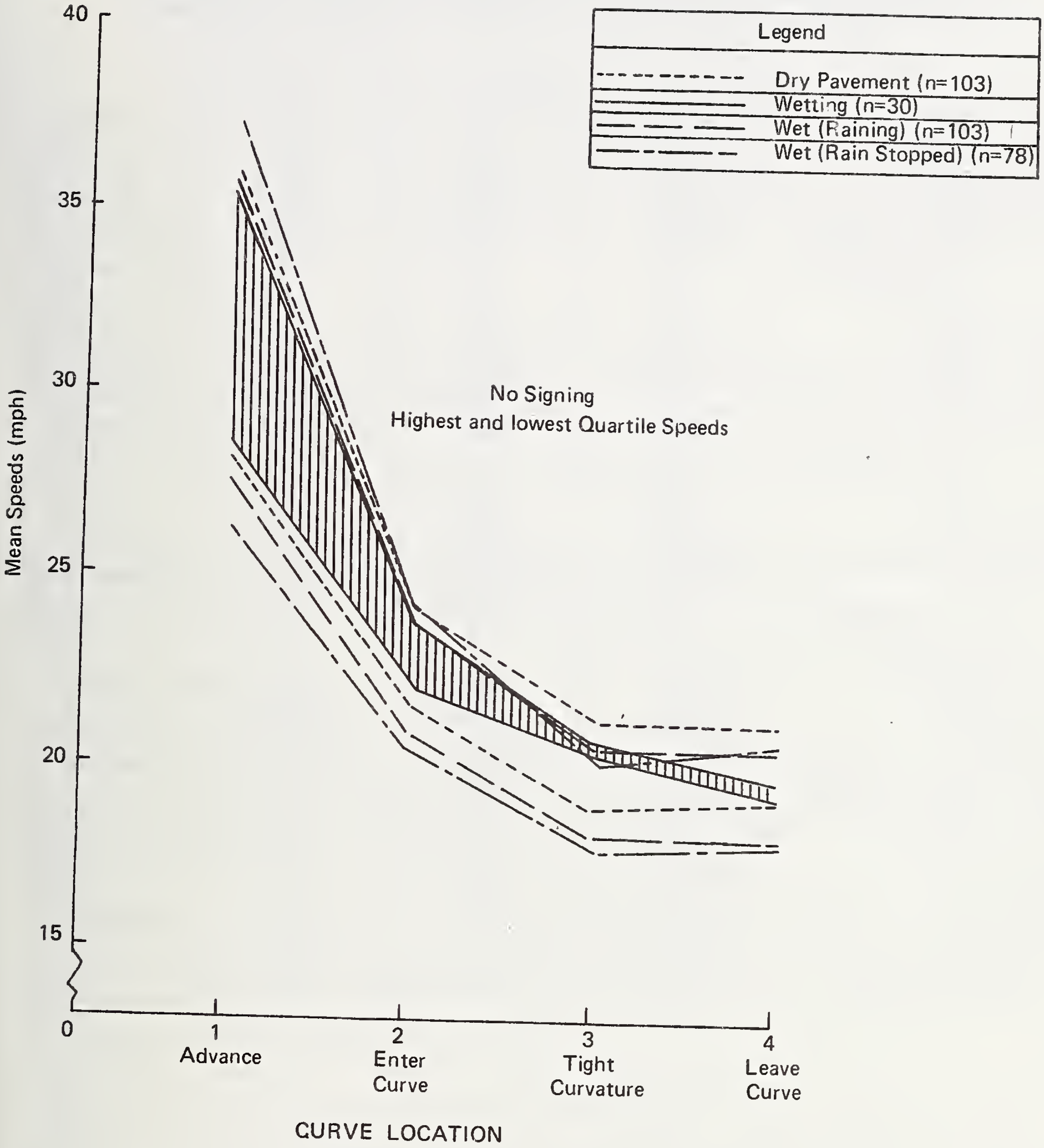


Figure 31. Mean speeds for highest and lowest quartile motorists during four conditions of pavement wetness, without signing.

Table 23
Summary of Data Collected During Ministudy to Examine Motorist's Responses to Pavement Wetting with Usage of Low Conspicuity, Low Specificity Signing
(*Indicates significant reduction from "dry" condition: $a \leqslant .05$)

	DRY	WETTING	WET		
NUMBER OF VEHICLES =	187.	21.	231.	150' Advance	Decelerating
MEAN SPEED, MPH=	32.31	33.93	32.12		
STD. DEV. SPEED =	5.20	2.97	4.05		
MEAN INTERVEHICLE GAP, FEET	688.87	732.38	503.08		
STD. DEV. GAP =	820.72	814.63	565.18		
MEAN ACCELERATION, F/S/S=	-.34	.39	-.33		
STD. DEV. ACCELERATION =	2.34	2.27	2.13		
NUMBER OF VEHICLES =	191.	25.	235.	Enter Curve	
MEAN SPEED, MPH=	23.07	22.21	22.19*		
STD. DEV. SPEED =	2.70	3.46	2.68		
MEAN INTERVEHICLE GAP, FEET	472.24	374.06	340.05		
STD. DEV. GAP =	522.57	453.41	391.44		
MEAN ACCELERATION, F/S/S=	-2.91	-2.88	-3.19		
STD. DEV. ACCELERATION =	2.02	1.83	3.18		
NUMBER OF VEHICLES =	189.	26.	236.	Tight Curvature	Cornering
MEAN SPEED, MPH=	20.05	19.13	19.09*		
STD. DEV. SPEED =	2.42	3.08	2.30		
MEAN INTERVEHICLE GAP, FEET	415.37	353.96	292.67		
STD. DEV. GAP =	478.63	438.44	343.91		
MEAN ACCELERATION, F/S/S=	-.32	-.05	.41		
STD. DEV. ACCELERATION =	2.92	3.40	2.50		
NUMBER OF VEHICLES =	188.	26.	117.	Leave Curve	Accelerating
MEAN SPEED, MPH=	20.50	19.64	19.96*		
STD. DEV. SPEED =	2.40	2.90	2.03		
MEAN INTERVEHICLE GAP, FEET	421.29	360.58	344.82		
STD. DEV. GAP =	483.01	438.94	398.17		
MEAN ACCELERATION, F/S/S=	2.16	1.61	2.17		
STD. DEV. ACCELERATION =	1.83	1.49	2.07		
NUMBER OF VEHICLES =	191.	26.	238.	Beyond Curve	
MEAN SPEED, MPH=	26.45	25.08	25.61*		
STD. DEV. SPEED =	3.21	4.15	3.11		
MEAN INTERVEHICLE GAP, FEET	540.23	445.01	389.31		
STD. DEV. GAP =	582.34	492.91	450.40		
MEAN ACCELERATION, F/S/S=	1.49	1.59	1.34		
STD. DEV. ACCELERATION =	1.63	1.51	1.50		

Table 24 presents the summary of TES data for the ministudy. Response differences from the other ministudies were observed due to the presence of high level signing. A notable reduction in speeds during the wetting period occurred throughout the curvature. The differences are most readily seen in Figure 32 whieh depicts mean speed plots for the highest and lowest quartile motorists. Comparisons with Figure 31 denote a significantly greater reduction in speeds exhibited by the faster motorists during the period of pavement wetting when high level signing was displayed. As the pavement underwent transition from the wetting to the wet condition, speeds of both quartiles increased. The faster vehicles did exhibit speeds nearly as high at the advance location as the corresponding sample during the "no signing" ministudy. The lower quartile motorists exhibited lower speeds, apparently as a result of the usage of high level signing.

Speeds for both quartile groups were significantly reduced in the tight curvature when high level signing was displayed. The speed reduction results in a nct change in behavior of those motorists leaving the curve from that of continuing to decelerate in thc no sign condition to that of accelerating out of the curve when high level signing is used.

The most pronounced effect during periods of pavement wetting, however, is that of reduced overall speeds and increased speed variability throughout the curve and its approach. To a lesser extent, the effect is also observed during the wet pavement condition.

Thus, the observed impact of signing on vehicle performance during pavement wetting is seen to be twofold. A tradeoff exists between motorists' slowing for the curve and the resulting increased variability in speeds. The fact that motorists did slow for the wet pavement indicates that the signing made them more aware of the hazard. On the other hand, a new hazard would apparently result from increased variability of speeds if signing were used consistently to warn of the skidding hazard. The data gathered in this study did not support an examination of headway violations to deal conclusively with the effects of increased speed variability. However, study observations did show that the maximum speed reductions (and induced variability in speeds) did occur in advance of the curve where long sight-distances tend to reduce the adverse effects associated with speed variation. Further, taking into account the nature of speed changes, it is important that the faster motorists were slowed to a greater extent than were the slower ones. It follows that the motorists who are most prone to cause a rearend accident (the extreme catastrophic consequence of speed variability) would receive the maximum remedial impact rendered by the device. This fact tends to reduce the possibility of adverse effects.

Table 24

Summary of Data Collected During Ministudy to Examine Motorists Responses to Pavement Wetting with Usage of High Conspicuity, High Specificity Signing (*Indicates significant reduction from "dry" condition: $a \leqslant .05$)

	DRY	WETTING	WET		
NUMBER OF VEHICLES =	301.	65.	77.	150' Advance	Decelerating
MEAN SPEED, MPH=	30.71	28.46*	30.00		
STD. DEV. SPEED =	4.38	4.96	4.62		
MEAN INTERVEHICLE GAP, FEET	525.54	573.15	519.01		
STD. DEV. GAP =	648.92	732.66	617.96		
MEAN ACCELERATION, F/S/S=	-.39	-.49	-.59		
STD. DEV. ACCELERATION =	2.01	2.01	2.02		
NUMBER OF VEHICLES =	292.	68.	79.	Enter Curve	
MEAN SPEED, MPH=	21.50	20.69*	20.86*		
STD. DEV. SPEED =	2.66	2.89	2.56		
MEAN INTERVEHICLE GAP, FEET	373.83	417.94	343.39		
STD. DEV. GAP =	475.42	549.72	434.76		
MEAN ACCELERATION, F/S/S=	-2.19	-1.74	-1.99		
STD. DEV. ACCELERATION =	1.74	1.75	1.46		
NUMBER OF VEHICLES =	284.	69.	77.	Tight Curvature	Cornering
MEAN SPEED, MPH=	19.06	18.46*	18.64		
STD. DEV. SPEED =	2.55	2.48	2.45		
MEAN INTERVEHICLE GAP, FEET	333.75	360.14	328.83		
STD. DEV. GAP =	428.92	493.57	421.26		
MEAN ACCELERATION, F/S/S=	1.26	1.48	.52		
STD. DEV. ACCELERATION =	2.22	3.88	1.64		
NUMBER OF VEHICLES =	295.	70.	76.	Leave Curve	Accelerating
MEAN SPEED, MPH=	19.62	19.24	19.25		
STD. DEV. SPEED =	2.55	2.24	2.47		
MEAN INTERVEHICLE GAP, FEET	333.51	368.28	343.56		
STD. DEV. GAP =	431.96	499.13	434.89		
MEAN ACCELERATION, F/S/S=	2.59	2.74	2.46		
STD. DEV. ACCELERATION =	2.26	2.11	1.59		
NUMBER OF VEHICLES =	304.	75.	81.	Beyond Curve	
MEAN SPEED, MPH=	25.20	25.15	25.44		
STD. DEV. SPEED =	3.50	2.83	3.00		
MEAN INTERVEHICLE GAP, FEET	417.76	456.80	433.49		
STD. DEV. GAP =	549.84	632.15	520.38		
MEAN ACCELERATION, F/S/S=	1.24	1.37	1.23		
STD. DEV. ACCELERATION =	1.80	1.69	1.62		

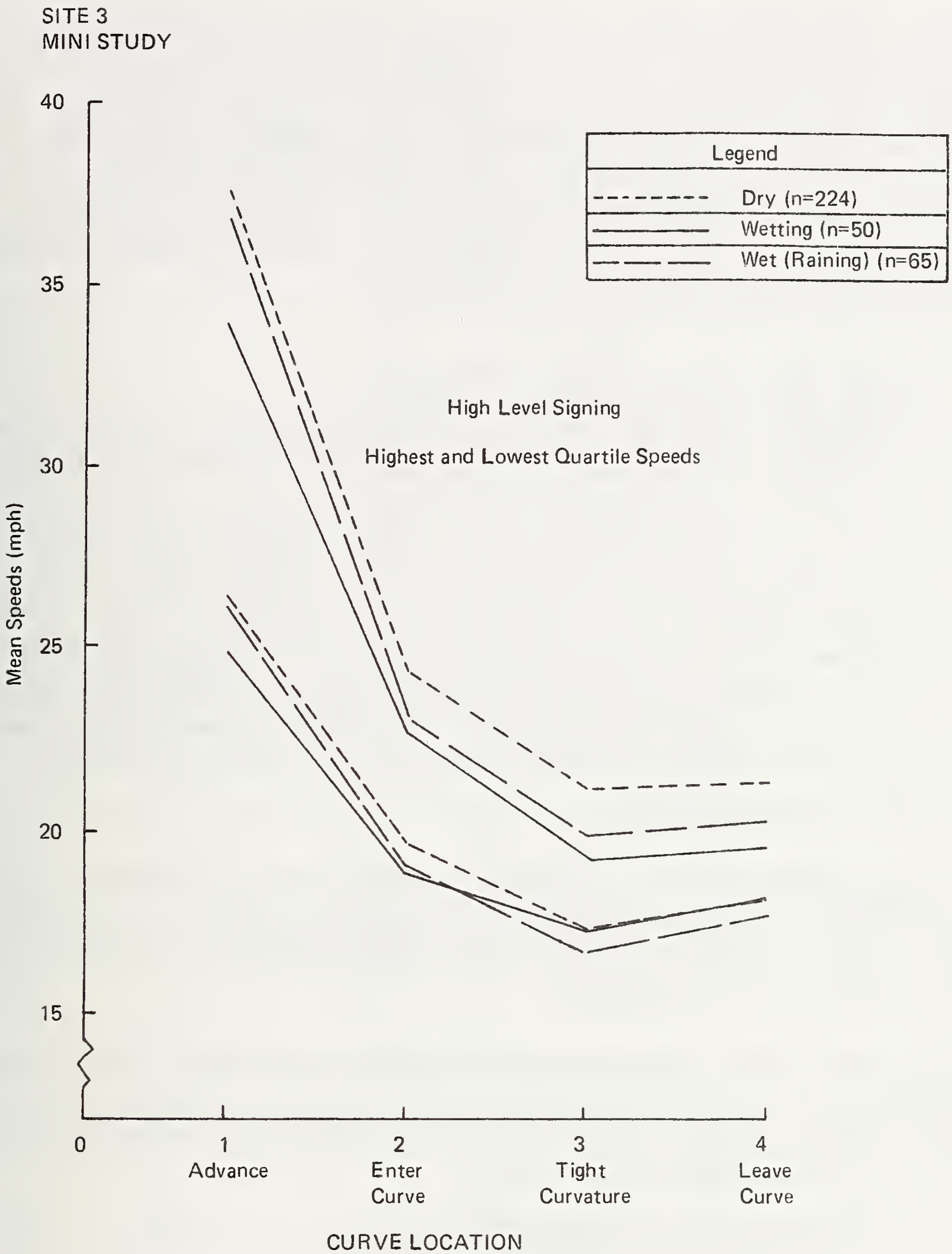


Figure 32. Mean speeds for highest and lowest quartile motorists during three conditions of pavement wetness influenced by high level signing.

Finally, when weighing benefits and drawbacks evidenced by the tradeoff, the relative consequence of each event must be considered. A skidding accident most often takes the form of the single vehicle "run off the road" type. The consequence of a fast moving vehicle striking an immovable object is inevitably severe. However, a rearend accident will occur at the relative differential speed of the two vehicles. Even at fairly high differential speeds of 10 to 15 mph (two standard deviations observed at the higher speed sites), the consequence will be less severe than skidding off the road at the traveled speed. In view of the tradeoff, it is suggested that overall effects of high conspicuity signing are favorable.

Traffic Evaluator System Data – (Icy Bridge Conditions)

Two approaches to a potentially icy bridge were used to gather data revealing motorists' responses to a series of warning signs. One bridge approach was characterized by long sight-distance geometry and the other by a short sight-distance. Data were collected on each approach at distances of 1,200 and 600 feet from the bridge, the bridge entrance point, and on the bridge at a distance of 150 feet beyond its entry point. Two sign locations were studied: bridge-located signs 150 feet from the bridge, and advance-located signs 1,000 feet in advance of the bridge. Both activated and nonactivated signing was tested during daylight hours and periods of predawn darkness. Ambient conditions were conducive to preferential bridge icing, and frost actually did occur during some periods of data collection. Data collection could not be accomplished during periods of extreme icing because of the hazard associated with stopping vehicles to be interviewed.

Eight signing schemes depicted in Figure 33 were tested during the hours shown. The times for data collection were determined such that two hours of data collection would precede sunrise and two hours would follow it. After winter Daylight Savings Time was initiated in early 1974, sunrise did not occur until 8:15 a.m.

Three-day data collection schedules were established as shown in Figure 33. The collection of baseline data on Day 1 permitted a sign versus no sign comparison for all experimental configurations. Effects of activation type and location were obtained by comparing Days 2 and 3 in each of four data collection periods as follows:

Period 1 – activation type at bridge location
Period 2 – activation type at bridge or advance location
Period 3 – activation type at both locations
Period 4 – activation type at advance location

Time: SITE 5	Time: SITE 4	Day 1	Day 2: Advance Location	Day 2: At Bridge	Day 3: Advance Location	Day 3: At Bridge
9:45–10:45 A.M.	6:00–7:00 A.M.	Baseline Data Collection		WATCH FOR ICE		ICE ON BRIDGE / WHEN FLASHING
8:30–9:30 A.M.	7:15 – 8:15 A.M.	Baseline Data Collection	BRIDGE ICY AHEAD	WATCH FOR ICE	WATCH FOR ICE ON BRIDGE	ICE ON BRIDGE / WHEN FLASHING
7:15–8:15 A.M.	8:15–9:30 A.M.	Baseline Data Collection	BRIDGE ICY AHEAD	ICE ON BRIDGE / WHEN FLASHING	WATCH FOR ICE ON BRIDGE	WATCH FOR ICE
6:00–7:00 A.M.	9:45–10:45 A.M.	Baseline Data Collection	WATCH FOR ICE ON BRIDGE		BRIDGE ICY AHEAD	

Figure 33. Schedule for testing icy bridge warning signs.

The confounding effect of having the first two periods occur in hours of predawn light conditions was dealt with by reversing the data collection schedule for the alternate site. TES measures of effectiveness for the warning sign were vehicle speed reductions and the locations of their occurrence in relation to the bridge. Another measure of effectiveness, questionnaire responses, is discussed in the next section of this report.

Site 4. The long sight-distance approach is discussed first. Motorists' responses to signing were generally not as favorable as those later observed on the short sight-distance approach. Two reasons which are related to approach roadway geometry contribute to this effect. First, the relative positioning of the signing with respect to motorists' field of view was less conducive to their observing the signing on this long tangent approach where wide shoulders necessitated a substantial lateral placement of the signs. Secondly, the bridge itself was a major competitor for motorists' attention, as it came into view prior to their reaching the advance sign.

Tables 25 and 26 present summaries of TES data which were gathered on 5 and 6 February, respectively. Mean speed variation is seen in many forms. First, the downgrade nature of the approach frequently causes an increase in speeds between the 1,200-foot and 600-foot advance speed-traps. Secondly, large standard deviations in mean speeds complicate the determination of the significance associated with observed difference. Finally, the large variation in speeds resulting from motorists' lower speeds due to darkness precludes a meaningful signing effects comparison across all conditions. Consequently, the primary difference observed from the tables is the significant mean speed reduction obtained between days during the first data collection period. The resulting finding is merely that activated signing performs better than nonactivated signing at the bridge location.

An attempt to compare the effects of all signs is seen in Table 27. An hour-for-hour comparison between each experimental signing condition and its corresponding time period in the baseline data does reveal relative effects of each signing condition. The table shows mean speed differences ranked so that the most effective signing condition is at the top, and statistically significant reductions are indicated. The result is somewhat suspect in that reductions in mean speed were noted for most signing conditions, which is rather unlikely and does contradict effects which have been shown in the literature. It is indeed likely that normative speeds were higher during the baseline data collection. However, the relative implied effects are noteworthy. A clear differential reduction in mean speeds is seen for the case of activated bridge signing used in combination with a nonactivated advance sign. Promising effects are also evident from other activated signs used singularly and in combination with nonactivated signing. An obvious overriding factor is the occurrence of daylight versus darkness, as evidenced by the fact that the combination of activated signing at both locations did not perform well during daylight hours. Questionnaire results confirm that fewer motorists saw signing during daylight hours.

Table 25

Summary of Data Collected on 5 February 1974 at Site 4

Site 4 — Long Sight-Distance Approach

	Advance Location: — / At Bridge: WATCH FOR ICE	Advance Location: BRIDGE ICY AHEAD / At Bridge: WATCH FOR ICE	Advance Location: BRIDGE ICY AHEAD / At Bridge: ICE ON BRIDGE (WHEN FLASHING)	Advance Location: WATCH FOR ICE ON BRIDGE / At Bridge: —	No Sign	
NUMBER OF VEHICLES =	56.	99.	100.	139.	65.	1200' Advance of Bridge (Bridge in View) and (Sign in View)
MEAN SPEED. MPH=	50.17	48.80	52.84	50.67	53.18	
STD. DEV. SPEED =	8.94	9.63	9.22	9.39	7.48	
MEAN INTERVEHICLE GAP, FEET	4345.54	2355.67	2585.57	1785.75	2211.32	
STD. DEV. GAP =	5552.81	2317.87	2698.80	2119.00	2015.84	
MEAN ACCELERATION, F/S/S=	-.80	.01	-.55	-1.90	-.18	
STD. DEV. ACCELERATION =	12.68	10.92	12.39	19.80	8.88	
NUMBER OF VEHICLES =	59.	102.	101.	141.	67.	600' Advance of Bridge
MEAN SPEED, MPH=	52.16	50.73	55.52	54.25	56.16	
STD. DEV. SPEED =	7.02	7.94	8.14	7.66	6.79	
MEAN INTERVEHICLE GAP, FEET	4390.10	2443.55	2881.30	1942.56	2302.48	
STD. DEV. GAP =	5713.27	2416.38	2947.78	2259.78	2187.19	
MEAN ACCELERATION, F/S/S=	.21	1.04	1.26	1.59	.22	
STD. DEV. ACCELERATION =	7.90	7.91	10.17	8.62	9.59	
NUMBER OF VEHICLES =	64.	106.	99.	142.	67.	Enter Bridge
MEAN SPEED, MPH=	44.36	44.73	46.46	48.35	50.43	
STD. DEV. SPEED =	10.92	9.64	10.57	9.38	9.08	
MEAN INTERVEHICLE GAP, FEET	3343.42	2089.41	2491.24	1682.07	2066.46	
STD. DEV. GAP =	3850.03	2504.95	2660.84	2018.83	1860.88	
MEAN ACCELERATION, F/S/S=	.32	-.06	-2.32	-.77	-.66	
STD. DEV. ACCELERATION =	6.29	5.58	7.06	6.60	6.91	
NUMBER OF VEHICLES =	65.	106.	100.	141.	67.	150' on Bridge
MEAN SPEED, MPH=	45.01	44.39	48.15	47.97	50.41	
STD. DEV. SPEED =	7.89	8.39	9.06	8.55	7.90	
MEAN INTERVEHICLE GAP, FEET	3523.62	2103.83	2477.35	1666.33	2070.48	
STD. DEV. GAP =	4068.67	2458.34	2599.92	1963.50	1839.68	
MEAN ACCELERATION, F/S/S=	.13	-.91	-2.04	-.67	-2.25	
STD. DEV. ACCELERATION =	8.27	8.05	7.07	7.02	6.75	
	Predawn	Predawn	Daylight	Bright Sun		

Table 26

Summary of Data Collected on 6 February 1974 at Site 4

Site 4 — Long Sight-Distance Approach

	Advance Location: (none) / At Bridge: ICE ON BRIDGE (WHEN FLASHING)	Advance Location: WATCH FOR ICE ON BRIDGE / At Bridge: ICE ON BRIDGE (WHEN FLASHING)	Advance Location: WATCH FOR ICE ON BRIDGE / At Bridge: WATCH FOR ICE	Advance Location: BRIDGE ICY AHEAD / At Bridge: (none)	No Sign	
NUMBER OF VEHICLES =	61.	111.	95.	127.	45.	1200' Advance of Bridge (Bridge in View) (Sign in View)
MEAN SPEED, MPH=	49.77	49.93	51.02	49.41	49.88	
STD. DEV. SPEED =	9.29	7.48	9.75	8.76	8.93	
MEAN INTERVEHICLE GAP, FEET	3905.16	2284.61	2603.21	1957.75	2852.25	
STD. DEV. GAP =	4344.72	2521.86	2400.22	1965.22	3088.02	
MEAN ACCELERATION, F/S/S=	-1.11	-.36	-.13	-.69	-.94	
STD. DEV. ACCELERATION =	11.09	7.53	9.14	8.77	10.76	
NUMBER OF VEHICLES =	58.	110.	102.	131.	44.	600' Advance of Bridge
MEAN SPEED, MPH=	49.79	51.76	54.57	51.66	54.39	
STD. DEV. SPEED =	7.66	7.19	6.77	7.63	6.91	
MEAN INTERVEHICLE GAP, FEET	4220.33	2364.15	2768.98	2024.42	3225.79	
STD. DEV. GAP =	5157.19	2669.33	2674.88	2095.28	3580.72	
MEAN ACCELERATION, F/S/S=	-.86	-.87	1.94	.32	.30	
STD. DEV. ACCELERATION =	7.05	8.36	8.21	6.75	11.49	
NUMBER OF VEHICLES =	66.	120.	102.	122.	47.	Enter Bridge
MEAN SPEED, MPH=	43.79	43.29	49.93	47.17	50.18	
STD. DEV. SPEED =	11.08	10.31	8.71	8.51	8.19	
MEAN INTERVEHICLE GAP, FEET	2665.64	1764.38	2503.21	1967.99	2700.44	
STD. DEV. GAP =	3276.66	1910.96	2369.51	1906.08	2978.63	
MEAN ACCELERATION, F/S/S=	.54	.14	-.70	.42	.35	
STD. DEV. ACCELERATION =	5.24	4.81	7.93	6.36	6.01	
NUMBER OF VEHICLES =	69.	118.	104.	123.	48.	150' on Bridge
MEAN SPEED, MPH=	41.35	43.22	49.12	46.96	50.21	
STD. DEV. SPEED =	6.91	8.93	7.61	7.12	6.51	
MEAN INTERVEHICLE GAP, FEET	2734.21	1733.05	2405.33	1950.62	2733.99	
STD. DEV. GAP =	3361.03	1555.22	2303.31	1884.36	2933.12	
MEAN ACCELERATION, F/S/S=	1.39	-.36	-.67	-1.43	-4.27	
STD. DEV. ACCELERATION =	4.95	5.58	7.29	7.67	9.65	

Table 27

Reductions in Mean Speeds Between Conditions of No Signing and Experimental Signing for Corresponding Times of Day (*Indicates significant reduction from normal condition: $a \leqslant .05$)

Advance Location	At Bridge	Ambient Condition	Speed Reduction: Bridge Entry	Speed Reduction: On Bridge
WATCH FOR ICE ON BRIDGE	ICE ON BRIDGE (WHEN FLASHING)	Dark	6.0*	5.9*
BRIDGE ICY AHEAD	WATCH FOR ICE	Dark	4.6*	4.7*
No Sign	ICE ON BRIDGE (WHEN FLASHING)	Dark	4.4*	4.5*
BRIDGE ICY AHEAD	No Sign	Daylight	4.2*	3.6*
WATCH FOR ICE ON BRIDGE	No Sign	Daylight	3.0*	2.6*
BRIDGE ICY AHEAD	ICE ON BRIDGE (WHEN FLASHING)	Daylight	2.4*	2.4*
WATCH FOR ICE ON BRIDGE	WATCH FOR ICE	Daylight	.9	1.5
No Sign	WATCH FOR ICE	Dark	.9	1.3

To seek verification or refutation of the cited differential effects, a more detailed examination is made of the driving samples. Figures 34 and 35 provide plots for respective darkness and daylight observations of mean speeds for both the total and highest quartile samples. Generally, high speeds at the 600-foot advance location are seen to result from the approach grade. No consistent effect on speeds at that location was exerted by the presence of either activated or nonactivated advance signing.

Interesting contrasts are noted between behaviors of the two samples, especially during hours of darkness. While total sample mean speeds are generally lowest at the bridge approach, the highest quartile group is still decelerating as it reaches the bridge. The faster motorists exhibit greater variability in speeds as they reach the bridge, and their overall approach decelerations are greater. Further, they generally exhibit greater differential decelerations in response to various signing conditions. The sharpest approach decelerations were observed for the activated sign located at the bridge during hours of darkness.

Certain inferences can be gained from the data shown in Figures 34 and 35 relating to the effect of the signing. Lowest speeds were obtained for activated signing located at the bridge and displayed during predawn darkness. Although the mean speeds were lower for the bridge sign used alone, the highest quartile group slowed more when the accompanying nonactivated advance sign was displayed. The nonactivated advance sign performed well when displayed by itself.

However, direct speed comparison is not the best criterion measure in this case due to possible day-to-day variations which could not be accounted for as no control site was available. To eliminate spurious effects, a final judgment of Site 4 results is based on overall speed reductions obtained for each sign between the 1,200-foot advance speed location and the bridge during each condition of darkness and daylight. The two signing schemes giving the best performance are the bridge-located activated sign by itself, and the combination of activated signs at both locations. Further comparisons of experimental signing effects are later discussed, based on observations for the other approach.

Site 5. An improved experimental method for examining icy bridge warning sign effects was applied at the short sight-distance approach; this was possible because a suitable control site was available. A bridge similar to that of the test site was located two miles upstream on US 340. Identical approach geometry between the two bridges created a well-suited experiment site-pair. As there were no major intervening access or egress routes, virtually the same sample of motorists who passed the control bridge was used as the test sample at the experimental site.

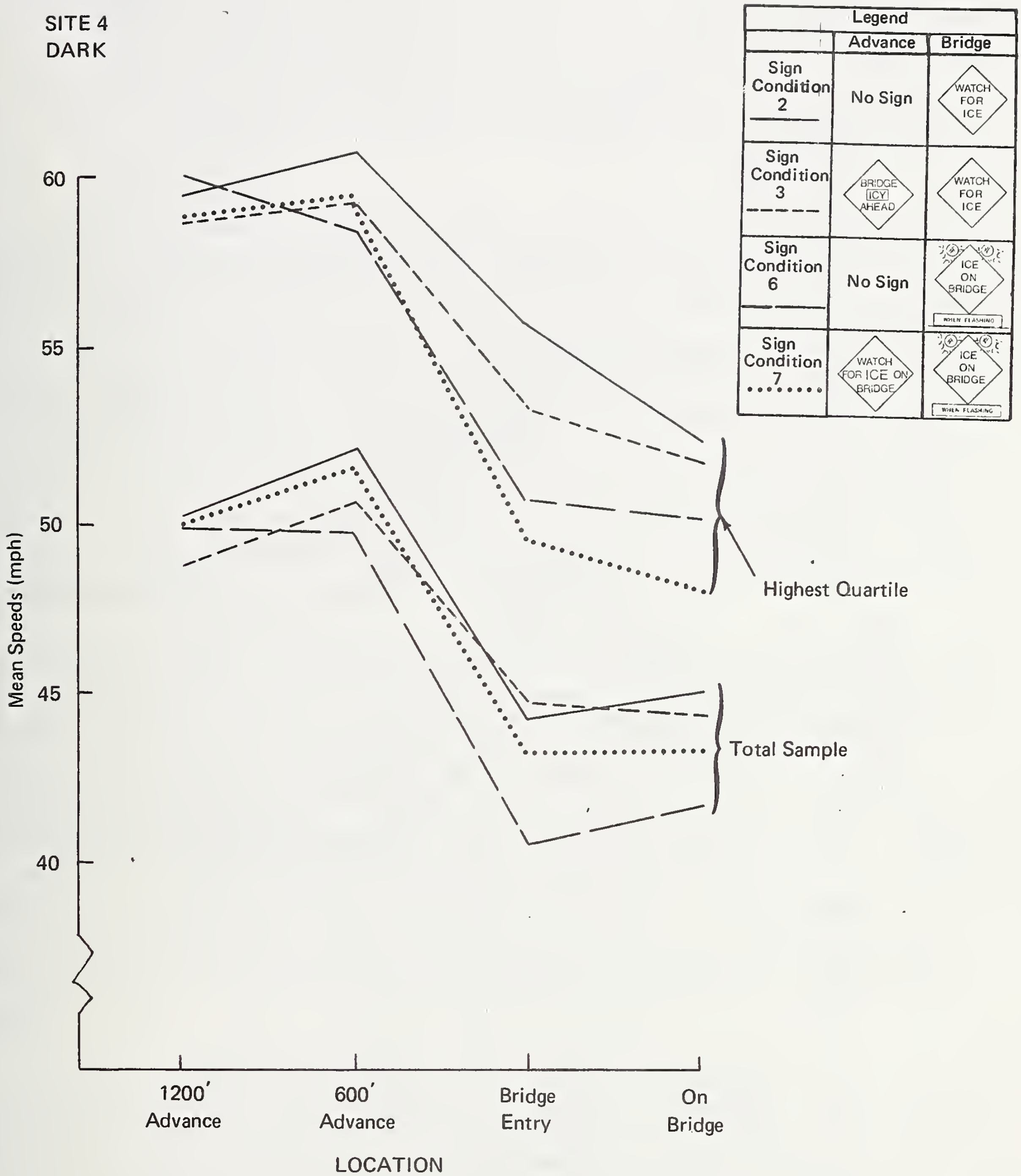


Figure 34. Mean speeds for both the total sample and highest quartile group, during predawn hours on the long sight-distance approach.

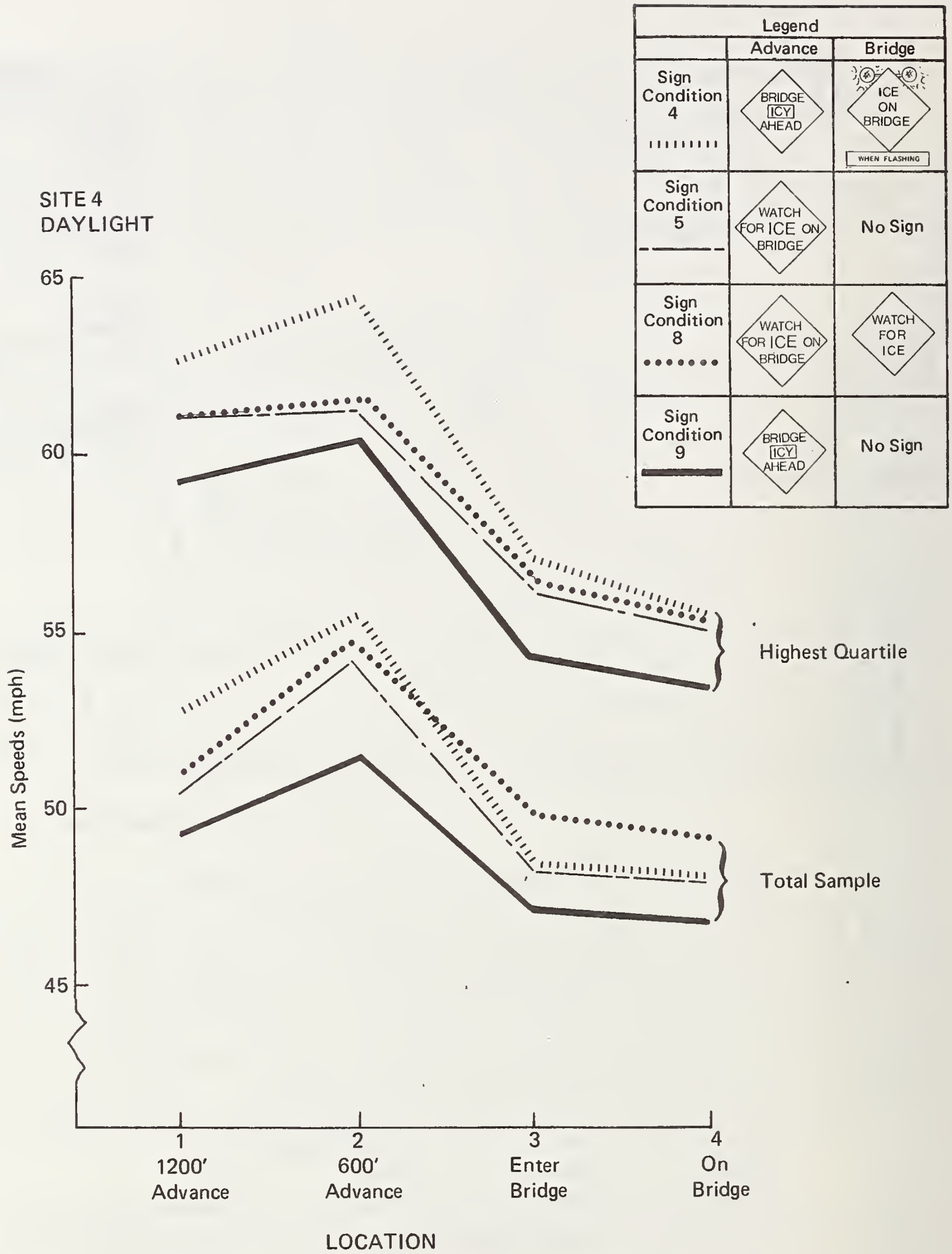


Figure 35. Mean speeds for both the total sample and highest quartile group, during daylight hours on the long sight-distance approach.

Vehicle performance data were gathered in a fashion similar to that for the long sight-distance approach so as to permit determination of the effects resulting from the sight-distance change. Speed data collection points and sign locations were at the identical distances from the bridge. The only procedural variation was to reverse the hourly schedule for signing scheme display so that the effects of darkness versus daylight could be examined for each condition.

Tables 28 and 29 provide summaries of TES sign evaluative data collected at both the experimental and control sites. Control site data was limited to the bridge entry location since it is the most critical point at which to examine motorists' sign responses. Direct speed comparisons were made between bridge entry points of the two sites for sign evaluation purposes, as "no sign" speed data at both sites indicated compatibility between the locations. It follows that the most illustrative indication of relative sign impact is the bridge entry speed difference between the sites. Those values, included in the tables, show that the use of two activated signs results in the maximum speed differential. This signing scheme performed better than that observed for the long sight-distance approach because it was used during hours of darkness. Signing offering the next best effect was the bridge-located activated sign, thus confirming its observed result on the long sight-distance approach.

For the sake of further verification and exploration of relative effects of all signing conditions, a comparison of between-signs effects among schemes tested each day shows significant bridge and bridge entry speed reductions for most activated conditions. Data at this site showed less variation resulting from the effects of daylight versus darkness. Comparing on an hour-for-hour basis between days, three expected findings were noted: (1) activated advance signing produced significantly greater speed reduction than did nonactivated advance signing (6 to 7 a.m.); (2) both activated signs produced better results than when both were nonactivated (7:15-8:15 a.m.); and (3) for activated and nonactivated signs used in combination, activation of the bridge sign produced better results than did activation of the advance sign (8:30-9:30 a.m.). Findings 1 and 2 were derived from conditions of darkness, and finding 3 was observed during daylight.

The above observations were based on mean speeds for the total vehicle sample. Keeping in mind that the fastest motorists are more suitably designated as the target sample, Figures 36 and 37 provide mean speed plots (during hours of darkness and daylight, respectively) for both the total and highest quartile samples. Data are somewhat incomplete because the 1,200-foot advance tapeswitch failed to adhere to the pavement on one morning. However, the lost data did not prove to be critical.

Table 28

Summary of Data Collected on 27 February 1974 at Site 5

Site 5 Short Sight-Distance Approach

	Advance Location: WATCH FOR ICE ON BRIDGE; At Bridge: (none)	Advance Location: BRIDGE ICY AHEAD; At Bridge: ICE ON BRIDGE WHEN FLASHING	Advance Location: BRIDGE ICY AHEAD; At Bridge: WATCH FOR ICE	Advance Location: (none); At Bridge: WATCH FOR ICE	
NUMBER OF VEHICLES =	(No Data Due to Switch Failure)				1300' Advance of Bridge (Advance Sign in View)
MEAN SPEED, MPH=					
STD. DEV. SPEED =					
MEAN INTERVEHICLE GAP, FEET					
STD. DEV. GAP =					
MEAN ACCELERATION, F/S/S=					
STD. DEV. ACCELERATION =					
NUMBER OF VEHICLES =	164.	156.	81.	106.	500' Advance of Bridge (Bridge Sign in View)
MEAN SPEED, MPH=	42.32	39.35	41.61	42.44	
STD. DEV. SPEED =	5.73	6.28	7.46	7.20	
MEAN INTERVEHICLE GAP, FEET	1106.12	1107.59	2595.03	2076.14	
STD. DEV. GAP =	1426.78	1342.37	3240.11	2671.42	
MEAN ACCELERATION, F/S/S=	.99	-.35	.62	-.46	
STD. DEV. ACCELERATION =	6.03	4.05	4.86	4.65	
NUMBER OF VEHICLES =	153.	160.	81.	113.	Enter Bridge
MEAN SPEED, MPH=	43.51 (Δ =.3)	35.39 (Δ =9.20)	42.76 (Δ =1.8)	43.07 (Δ =2.0)	
STD. DEV. SPEED =	4.51	6.20	6.22	6.87	
MEAN INTERVEHICLE GAP, FEET	1203.61	971.30	2625.30	2161.14	
STD. DEV. GAP =	1553.80	1119.18	3293.92	2741.55	
MEAN ACCELERATION, F/S/S=	.25	-.45	.26	-.38	
STD. DEV. ACCELERATION =	6.45	3.60	4.57	3.98	
NUMBER OF VEHICLES =	156.	164.	79.	110.	150' on Bridge
MEAN SPEED, MPH=	43.77	35.18*	42.46*	43.47	
STD. DEV. SPEED =	4.89	6.53	5.63	6.73	
MEAN INTERVEHICLE GAP, FEET	1205.78	964.54	2552.83	2235.39	
STD. DEV. GAP =	1527.45	1119.04	3346.03	2740.93	
MEAN ACCELERATION, F/S/S=	-1.21	-.81	-1.40	-1.08	
STD. DEV. ACCELERATION =	5.69	7.82	4.75	6.15	
	Predawn	Predawn Moderate Frost	Daylight	Daylight	

Δ = Difference from Control (mph)

CONTROL SITE — No signing

	Predawn	Predawn Moderate Frost	Daylight	Daylight	
NUMBER OF VEHICLES =	163.	145.	79.	126.	Enter Bridge
MEAN SPEED, MPH=	43.78	44.59	44.57	45.08	
STD. DEV. SPEED =	5.68	5.08	6.40	5.88	
MEAN INTERVEHICLE GAP, FEET	1172.46	1354.02	2838.69	2144.80	
STD. DEV. GAP =	1409.65	1629.18	3154.06	2458.74	
MEAN ACCELERATION, F/S/S=	-2.18	-1.23	-2.92	-1.99	
STD. DEV. ACCELERATION =	6.99	5.81	5.78	5.13	

Table 29

Summary of Data Collected on 28 February 1974 at Site 5

Site 5 Short Sight-Distance Approach

	Advance Location: BRIDGE [ICY] AHEAD; At Bridge: (none)		Advance Location: WATCH FOR ICE ON BRIDGE; At Bridge: WATCH FOR ICE		Advance Location: WATCH FOR ICE ON BRIDGE; At Bridge: ICE ON BRIDGE (WHEN FLASHING)		Advance Location: (none); At Bridge: ICE ON BRIDGE (WHEN FLASHING)		
NUMBER OF VEHICLES = MEAN SPEED, MPH= STD. DEV. SPEED = MEAN INTERVEHICLE GAP, FEET STD. DEV. GAP = MEAN ACCELERATION, F/S/S= STD. DEV. ACCELERATION =	215. 43.79 6.69 1052.07 1316.59 -.59 5.24		209. 43.92 6.64 1097.88 1562.56 -1.05 4.78		91. 44.76 7.38 2520.80 2496.10 -1.04 5.12		129. 44.72 6.35 1716.74 2025.80 -.94 4.56		1300′ Advance of Bridge (Advance Sign in View)
NUMBER OF VEHICLES = MEAN SPEED, MPH= STD. DEV. SPEED = MEAN INTERVEHICLE GAP, FEET STD. DEV. GAP = MEAN ACCELERATION, F/S/S= STD. DEV. ACCELERATION =	195. 42.53 5.44 1107.56 1319.93 -.28 5.27		211. 41.26* 6.67 994.43 1374.85 .33 4.67		95. 40.94 8.72 2281.02 2722.97 9.33 89.14		122. 43.42 6.74 1708.67 2166.42 .55 4.24		500′ Advance of Bridge (Bridge Sign In View)
NUMBER OF VEHICLES = MEAN SPEED, MPH= STD. DEV. SPEED = MEAN INTERVEHICLE GAP, FEET STD. DEV. GAP = MEAN ACCELERATION, F/S/S= STD. DEV. ACCELERATION =	192. 42.51 5.14 1135.92 1405.21 -.03 5.43	Δ =2.0	207. 43.15 5.21 1077.13 1455.51 -.32 5.24	Δ =.2	98. 39.27 8.32 2146.73 2610.32 .26 3.18	Δ =4.9	123. 41.80 5.54 1719.39 2109.96 .14 3.47	Δ= 3.9	Enter Bridge
NUMBER OF VEHICLES = MEAN SPEED, MPH= STD. DEV. SPEED = MEAN INTERVEHICLE GAP, FEET STD. DEV. GAP = MEAN ACCELERATION, F/S/S= STD. DEV. ACCELERATION =	193. 42.73 5.34 1144.98 1402.22 -.56 6.50		205. 42.68 5.09 1082.66 1451.99 -1.39 5.85		99. 40.36 7.86 2185.81 2647.42 -.47 4.97		120. 42.18 5.86 1766.25 2120.80 .09 6.32		150′ on Bridge
	Predawn		Predawn Light Frost		Daylight		Bright Sun		

Δ =Difference from Control (mph)

CONTROL Site-No Signing

NUMBER OF VEHICLES = MEAN SPEED, MPH= STD. DEV. SPEED = MEAN INTERVEHICLE GAP, FEET STD. DEV. GAP = MEAN ACCELERATION, F/S/S= STD. DEV. ACCELERATION =	192. 44.52 5.48 1164.01 1416.69 -1.11 4.77	189. 43.40 5.31 1211.63 1557.38 -1.58 5.32	104. 44.19 7.47 2203.50 2427.57 -1.16 3.94	125. 44.97 5.64 1756.44 2141.89 -.96 5.86	Enter Bridge

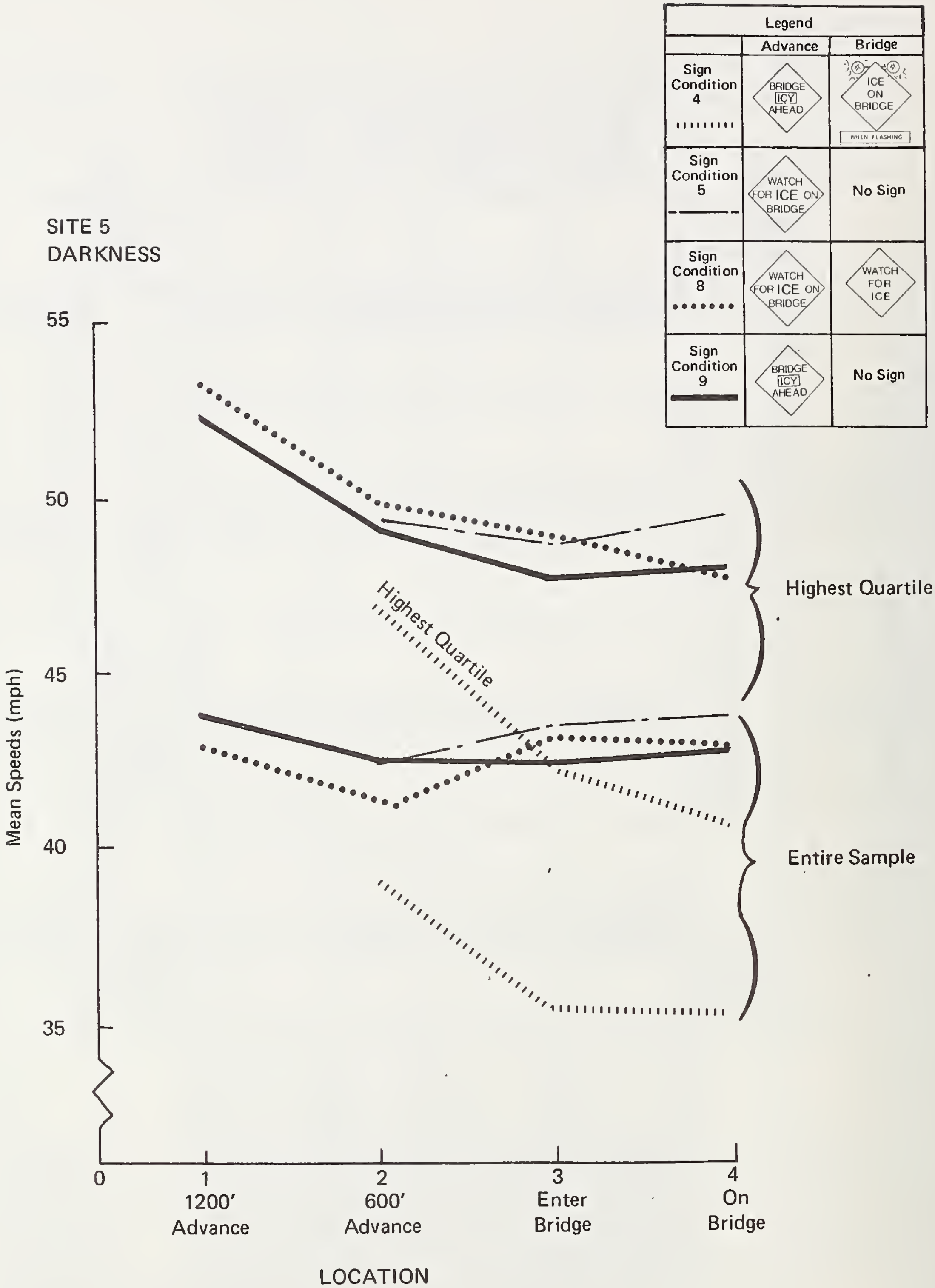


Figure 36. Mean speeds for both the total sample and highest quartile group, during hours of darkness on the short sight-distance approach.

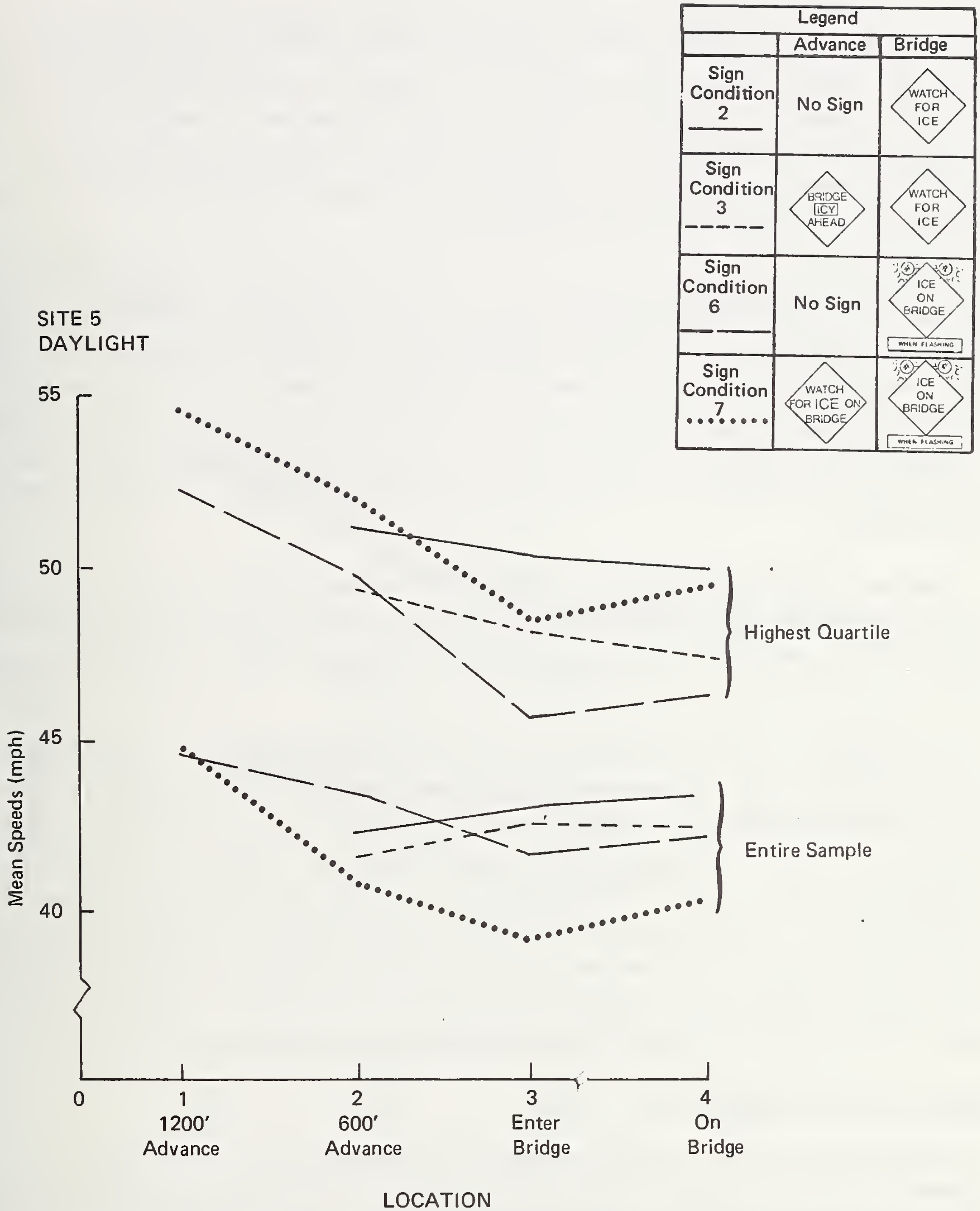


Figure 37. Mean speeds for both the total sample and highest quartile group, during daylight hours on the short sight-distance approach.

Most notable in Figure 36 is the extreme speed reduction resulting from use of activated signs at both the bridge and the advance position. Attention should be called to the fact that ambient conditions were highly conducive to such a response to the signing. Its conspicuity was increased during darkness, and its perceived credibility was enhanced by the occurrence of moderate frost. Further note must be made of concurrent speeds at the control site. The higher than average speeds, representing a slight increase from the preceding hour, indicates that motorists were not concerned about the potential hazard in the absence of signing.

Relatively closer grouping of mean speeds was noted for the remainder of the sign conditions tested during hours of darkness with the nonactivated advance sign affording the least speed reduction. In fact, average speeds for the total sample increased at the bridge approach during use of both nonactivated signing schemes. Highest quartile motorists slowed slightly for the nonactivated advance sign, but then increased speed. The combination of two nonactivated signs caused continual slowing on the part of the highest quartile motorists, yet speeds remained high. The activated advance sign did cause motorists to slow down but to an insignificant degree compared to both nonactivated signing.

Response to signing under daylight conditions, seen in Figure 37, indicates poor results obtained with the nonactivated sign. Better results were generally obtained with the bridge-activated rather than the advance-activated sign. The single exception is the highest quartile responses to the bridge-activated sign used in concert with the nonactivated warning.

As the criticality of distinguishing between the relative merits of advance – versus bridge – located activated signs (due to the cost of providing both) was obvious, a further analytical step was taken. Figure 38 provides plots of adjusted mean speeds for both the total and the highest quartile samples for all signing conditions containing a single activated sign. Adjustments were based on speed differences at the control site in an attempt to correct for any spurious effects on speeds. As seen from the figure, closer groupings were obtained for both average and highest quartile speeds. Lower bridge entry speeds were obtained for both the average and highest quartile speed samples with the use of bridge-activated signing rather than with advance-activated signing. The result is strong evidence to support the use of activated signing located at the bridge.

Overview and Recommendations

An examination of eight experimental signing combinations comprised of activated, nonactivated, advance- and bridge-located signs was conducted at two bridge approaches. In all cases, activated signing elicited greater speed reductions than did nonactivated signing. Of the nonactivated signing observed, the advance "Watch for Ice on Bridge" sign provided better results than the "Watch for Ice" sign at the bridge. Undoubtedly, the bridge competed for driver attention and negated any effect of the latter sign.

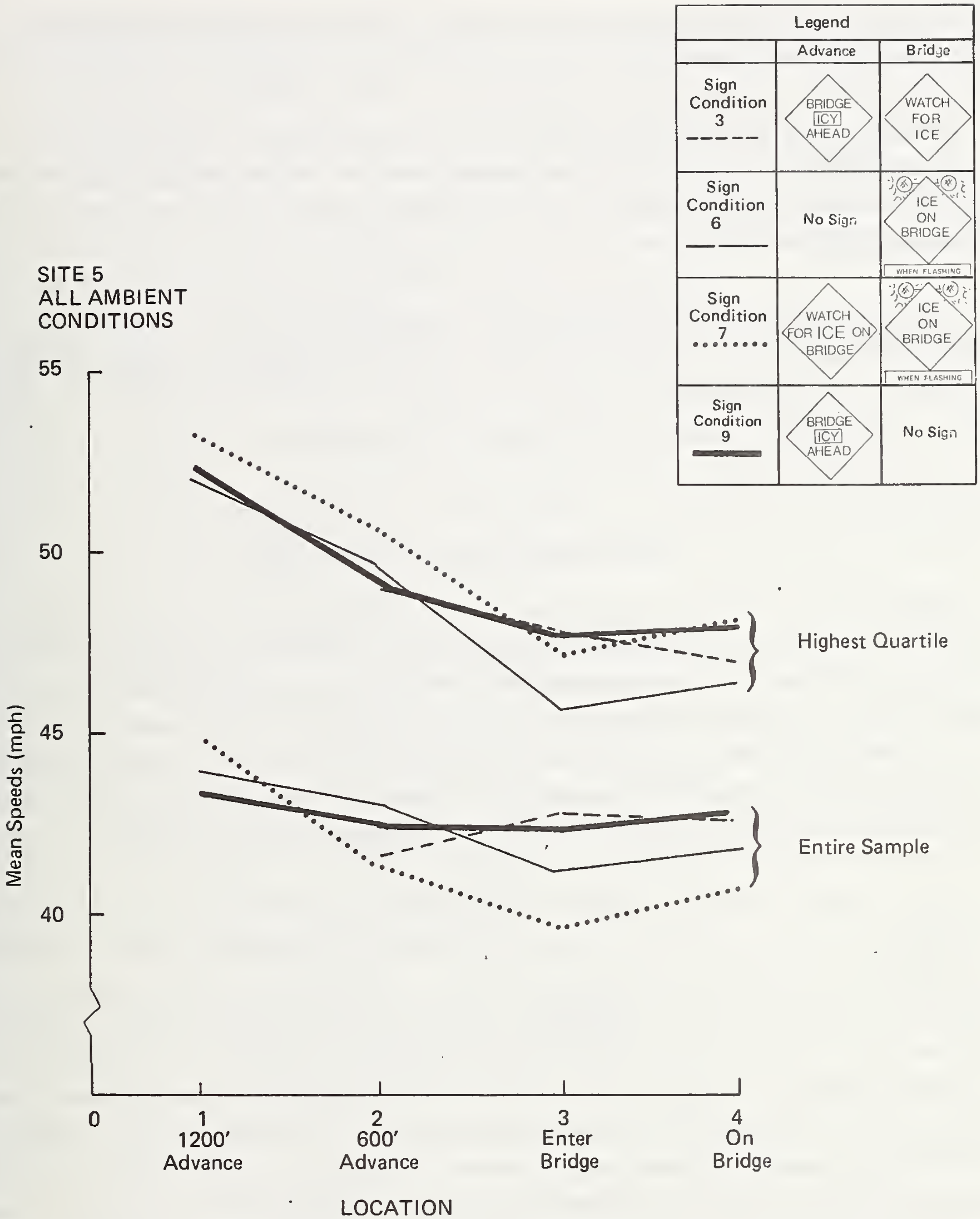


Figure 38. Adjusted mean speeds of entire data sample and highest quartile group for all experimental signing conditions containing one activated sign at Site 5.

Improved responses to signing were obtained at the short sight-distance bridge approach. Better overall responses were obtained during the hours of darkness.

The sign condition eliciting the maximum speed-reducing effect consisted of activated signing at both advance and bridge locations during hours of darkness. Bridge-located activated signs elicited larger speed reductions than did advance-located activated signs during both conditions of daylight and darkness.

Therefore, based on all observations, the recommended icy bridge warning condition consists of activated signing at both the advance and bridge locations. As a less costly alternative, the activated, bridge-positioned sign combined with the advance "Watch for Ice on Bridge" sign is recommended, based on its performance in this study.

Questionnaire Analysis – Rain Sites

Interviewing of motorists was conducted during conditions of wet and dry pavements, with and without the presence of experimental signing. Speed data for each vehicle were unobtrusively gathered using pavement tapeswitches at various points throughout the curve and matched to the appropriate questionnaire responses for purposes of analysis. Interview sites were located beyond driver sight-distances from the curve; in this way, unbiased speed data were obtained. Vehicles selected for motorists' interviews were those exhibiting sufficient headways such that their speeds were not influenced by others in the traffic stream.

An interviewing strategy was adopted which permitted certain driver characteristic data to be obtained before the driver knew that the study related to potential skid hazard. After a brief introduction which advised the motorist that a safety study was being conducted, general questions were asked to derive his familiarity with the site and the level of his driving practice. More specific questions were then asked regarding his assessment of the posted speed limit and his estimation of safe driving speed at that site during wet pavement conditions. By this time, the motorist knew the study pertained to potential skidding maneuvers. Questions were then asked regarding his skidding experience both at the site and within his overall driving experience. The driver was asked whether or not he thought the site was a potential skid hazard and, if so, what his cue of the hazard was. In cases where the experimental sign was not cited as the cue, the driver was asked if he had seen a sign warning of a possible skid hazard. If he had, he was asked to identify the sign by describing its appearance and message and to rate the sign as being helpful or not helpful.

The verbally-administered portions of the interview outlined above took about four minutes per vehicle. Cooperative drivers were asked to fill out a short attitudinal questionnaire to determine their expressive self-testing profiles. The form was accompanied by a disclaimer stating the answers that were to be used for research purposes only. The questions pertained to the driver's feelings about driving fast on two-lane rural roads, about passing while driving at high speeds, about proneness to calmness or panic in the event of an unexpected skid, and to the driver's rating of the site as being dangerous as a skid hazard. Answers to these questions were placed on a plus-to-minus scale to provide uniformity of analysis.

While motorists filled out their portion of the questionnaire, the interviewer recorded data descriptive of the vehicle and driver.

Questionnaire information with matched vehicle speed data was coded onto punched cards and classified as 40 variables. Vehicular speeds were collected at five points: 1) 200 feet in advance of the curve, 2) entering the curve, 3) tight curvature, 4) leaving the curve, and 5) 200 feet beyond the curve. Relationships between all variables were derived using Program MISSIN, recently developed at BioTechnology, Inc.

This computer program is designed to accept up to 50 data elements on each of an unlimited number of subjects. Missing (or unknown) data elements are permitted. The number of subjects, variable means, standard deviations and the Pearson product-moment correlations are computed for each pair of variables. The significance level of the correlations is calculated. Variables are grouped into clusters of variables having uniform correlations and high internal consistency. The correlation matrix is reordered to present the clusters of high intercorrelation along the diagonal. Up to nine sets of data may be processed during one program run. As many as nine copies of the tables may be printed. The program runs on CDC-6000 series computers and is written in Fortran Extended.

Samples of the interview forms used are found in Appendix A, and Appendix C which is a separate volume provides a complete listing of Program MISSIN output.

An examination of motorists' responses relative to the skid hazard and the effect of experimental signing on those responses is included in the discussion which follows. A matrix depicting 26 relevant variables and a diagrammatic representation of significance obtained between each pair is given as Figure 39. Variables are assigned to the following categories: signing, pavement condition, driver responses to signing, general driver characteristics, vehicle characteristics, and observed vehicle speeds. Dots in the matrix cells represent significant

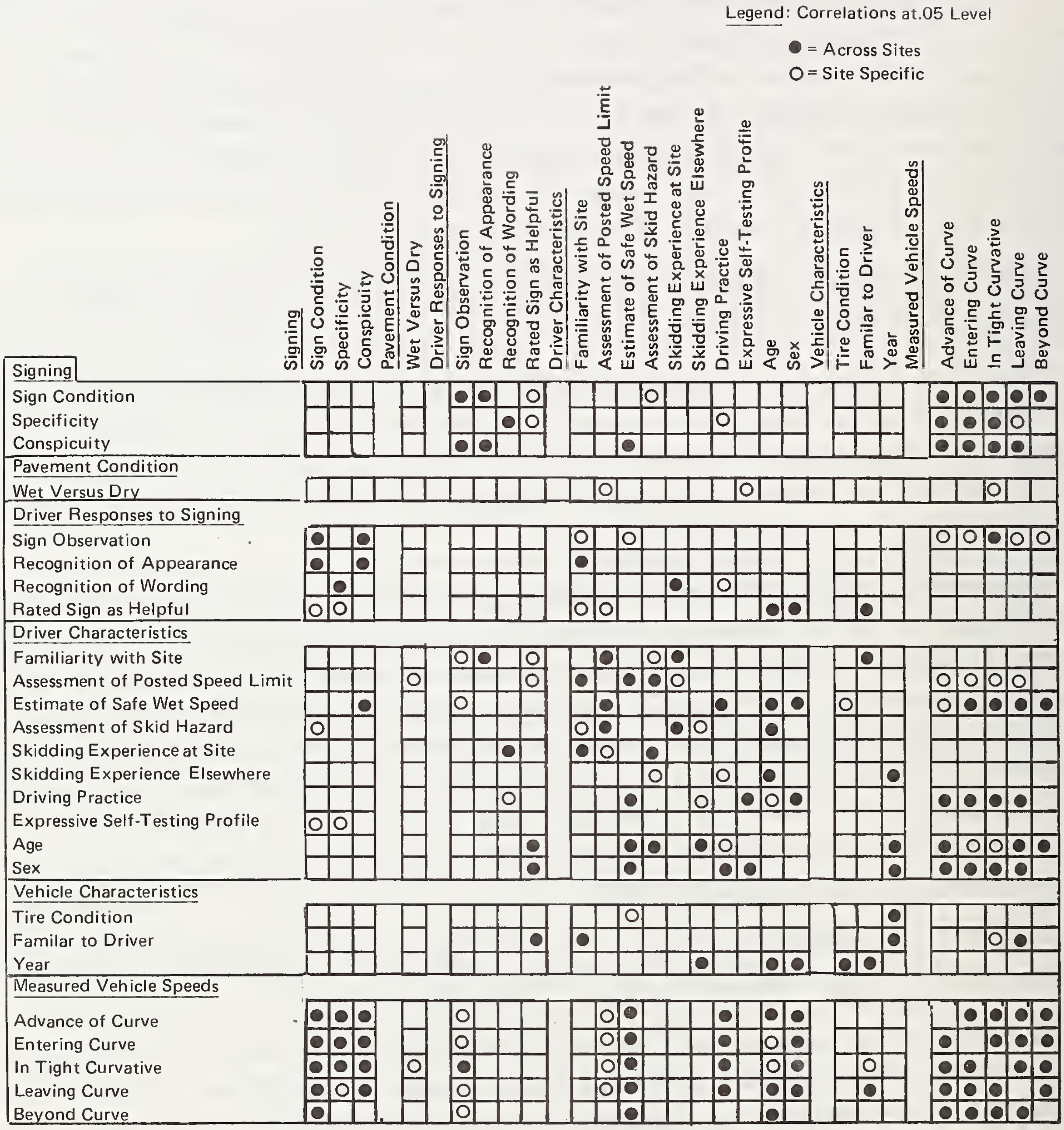


Figure 39. Matrix of 26 relevant variables depicting significance obtained between each pair.

correlations, at the .05 level or better, obtained between the corresponding variable pairs. Black dots indicate relationships obtained for two or more sites; white dots indicate relationships valid for a single site.

Most of the derived relationships were obtained at either Site 1 or Site 3. The Site 2 sample was limited due to road tapeswitch failures during wet pavement conditions, and few correlations were obtained because of the small sample size.

Signing Variables

Sign Condition. Ranking of signing from low to high level was determined by combined levels of increasing specificity and conspicuity. The "no sign" condition, or zero specificity and conspicuity, was the lowest condition. Low specificity signing consisted of the symbol sign panel with no wording. Moderate specificity called for the driver to slow down when the pavement was wet or the attached beacons were flashing. High specificity called for the driver to slow to a given advisory speed limit. Conspicuity was simply rated as low or high depending upon use of the flashing beacons.

The signing condition level, ranging from no sign to combinations of high specificity and conspicuity, correlated with a number of variables processed in the questionnaire analysis. They are indicated in the top row in Figure 39. The following discussion of variable relationships will be generally ordered by reading the matrix rows from left to right.

Drivers at all three sites were more prone to observe and properly identify the appearance of the higher level signing. The proper identification of sign wording did not increase with higher level signing. An inference can be made that the more conspicuous signing called attention to itself but did not consistently arouse motorists' attention to the point of their retaining the sign's wording. The influence of conspicuity, discussed later, will tend to confirm the logic of this inference.

Higher level signs were considered more helpful than lower level signing by motorists at one site. However, at another site, motorists were significantly less likely to assess the site as a skid hazard during the presence of the higher level signing. A potentially adverse effect of signing might be realized in this case if motorists were to construe signing as making the site safer.

The higher level signing conditions did elicit generally lower vehicle speeds for interviewed motorists at sites 1 and 3. Higher correlations between sign conditions and vehicle speeds were noted at the more critical positions in the curves (e.g., entering as opposed to leaving the curve). Emphasis should be given to the fact that magnitudes of observed speed reductions were small and that impact of thc signing or speeds was discussed in the previous section of this report.

Specificity. Motorists' proper identification of sign message was observed more frequently with use of higher specificity signing. This is the result of the motorists' apparently increased tendency to recall specific advisory speed limits as they were used for high specificity signing. Similar observations have been cited in the literature (Hakkinen, 1965). In order to be credited for a proper response to sign message, the interviewed motorists had to identify the most specific meaning conveyed by the sign. For example, "slow" would not surface as a correct response if displayed sign wording read "Slow When Wet".

At one site, more specific signing was viewed by motorists as being more helpful. Further, increased specificity resulted in reduced vehicle speeds at the advance, entering, and tight curve locations at both Sites 1 and 3. Speed reductions were also noted for motorists leaving the curve at Site 3.

Conspicuity. The use of highly conspicuous signing conditions resulted in significantly more motorists seeing and correctly identifying the sign at both Sites 1 and 3. Motorists at those sites also gave lower estimates of safe wet speeds when highly conspicuous signs were displayed.

High conspicuity resulted as well in lower speeds at all sites. The relative effects of specificity and conspicuity were reflected by their respective correlation coefficients with vehicle speeds. Thc impact on speed reduction of increased conspicuity was greater than that of increased specificity for all curve locations. The fact that increased conspicuity did not correlate with increased motorists' recognition of sign wording implies a reduction of speed due merely to the presence of the flashing beacons.

Pavement Condition Variable

The lone descriptor of pavement condition is whether it was wet or dry. An accelerometer was used in an attempt to distinguish between degrees of slipperiness during wet pavement conditions; the attempt was not successful. The wet pavement condition is defined as characterized by the presence of light water film with no visible drying taking place. By contrast, dry pavement data were collected during conditions of complete dryness when no rain had fallen for days.

Pavement Wetness. The effect of wet pavement was seen at one site in the motorists' scalar rating of skidding danger associated with prevailing conditions. Motorists rated the site as being more hazardous during conditions of wet pavement. Interviewed motorists' speeds were generally lower during wet pavement data collection periods; however, the difference was statistically significant only in the tight curvature at Site 1. Speed data for the total driver (interviewed and noninterviewed) population, discussed previously in this report, did show other significant speed differences.

Drivers' Responses to Signing

Motorists' responses in measures other than vehicle speeds consisted of: (1) whether or not they had seen a skid hazard warning sign, (2) proper or improper identification of the sign's appearance and message, and (3) whether or not they thought the sign was helpful. Expansion and clarification were obtained on point 3 by asking how the sign was helpful.

As indicated earlier, motorist's proper response to sign wording required his correct identification of the most specific wording displayed at the time of the interview. Recognition of the sign appearance was taken as identification of sign color, shape, flashing lights, or symbol such that the questionnaire scorer knew that the driver had seen the test sign. Interviewer bias was eliminated from the analysis, since the interviewers were not informed of the specific signs being displayed.

Sign Observation. Thc use of higher level and high conspicuity signing conditions resulted in more motorists observing the signing at all sites. The percentages of interviewed motorists who observcd experimental signing are given in Table 30 by sign type and pavement condition. No significant differences werc noted between motorists' obscrvation rates among the conspicuous signing conditions.

Table 30

Percentages of Interviewed Motorists Who Observed Experimental Signing, by Sign Type and Pavement Condition

		 Condition # 2	 Condition # 3	 Condition # 4	 Condition # 5	 Condition # 6
Dry Pavement	Saw Sign	31	46	55	55	65
	Appearance	75	75	94	100	95
	Message	38	58	56	50	76
Wet Pavement	Saw Sign	37	29	83	73	72
	Appearance	62	60	100	100	100
	Message	69	65	55	82	73

Experimental signing was more often seen by more familiar motorists at Site 1. There was no correlation between motorists' site familiarity and sign observation at the other two sites. That unfamiliar motorists are more or less likely to see a warning sign is representative of a general information gap in the literature (Svenson, 1968). An examination was therefore made of the data for "first time" motorists; it revealed a small sample (23 drivers-about 6 percent of the population) that was almost evenly split with 44 percent having seen the sign.

Motorists at Site 2 who saw the sign gave a lower estimate of safe wet weather driving speed. Motorists' sign observation also impacted on their speeds. Those drivers who saw the experimental signs negotiated the entire curve at lower average speeds at Site 3 and slowed for the tight curvature at Site 2.

Recognition of Sign Appearance. Higher level and more conspicuous signs prompted more motorists to correctly identify sign appearance. Of those motorists seeing the test signs, the more familiar were more prone to properly identify the sign's appearance. This finding is consistent with that of the more familiar motorists' being more likely to observe the signing.

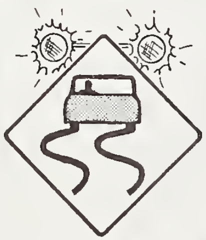
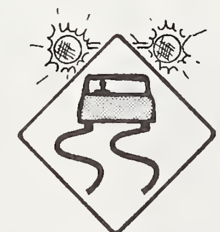
Recognition of Wording. The use of higher specificity signing resulted in more motorists' properly recalling the sign's wording at all sites. Motorists who reported prior skidding experience at Sites 1 and 3 were less likely to recognize wording on the test signs. Drivers at Site 3 who drove fewer miles per year were more likely to recognize the sign wording. There were no correlations between motorists' speeds and their having properly read the test signing.

Assessment of Test Sign as Helpful. Higher level and more specific signing was rated as being more helpful by Site 3 motorists. Motorists at Site 3 who thought the posted speed limit should be higher were less prone to regard the test sign as helpful.

Table 31 denotes percentages of interviewed motorists who rated the signs as helpful by sign conditions and pavement wetness. Sign conditions 5 and 6 were generally considered as the most helpful, and all signing was rated as helpful by more drivers during wet pavement conditions. Of the 33 motorists who saw signs 5 or 6 at Site 3, all but two thought the sign was helpful. Across all sites, the sign considered to be most helpful was sign 6; 88 percent of the sample thought so. Sign 5 was next with 85 percent. Test signing was more often designated as being helpful by older, male (Sites 1 and 3), and more familiar (Site 2) motorists. At all sites, those motorists who were driving vehicles with which they were not familiar were more prone to assess the test signing as being helpful.

Table 31

Percentages of Interviewed Motorists Who Rated Experimental Signing as Being Helpful, by Sign Type and Pavement Condition

	 Condition # 2	 SLOW WHEN WET Condition # 3	 Condition # 4	 SLOW WHEN FLASHING Condition # 5	 MAX SPEED X MPH Condition # 6
Dry	71%	75%	61%	82%	94%
Wet	85%	89%	100%	91%	83%

It is noteworthy that motorists who designated the signing as being helpful did not drive through any test sites at significantly lower speeds. A number of motorists, when asked how the sign was helpful, said that they had slowed down as a result of it. A spot check of the data revealed that most of those drivers actually did reduce their speed. Numerous other drivers, who said that the sign was a helpful reminder of the curve, did not exhibit significant slowing compared to the total population.

Driver Characteristics

An examination of the driver in terms of selected demographic characteristics, driving experience items, and site hazard observations was used in the analysis of motorists' responses to experimental signing and the prevailing skid hazard.

Motorist's familiarity with the site was coded by grouping responses into one of five categories descriptive of the frequency with which he drove through the site. Current driving practice was measured by the motorist's approximation of his annual mileage driven. Site-related and general skidding experience of the motorist was coded according to its occurrence by pavement conditions and roadway geometry. To determine the motorist's cue of potential skidding hazard, he was asked if and why he thought the site was a skidding hazard under the prevailing conditions. Responses were classified by whether or not the driver perceived the site as a potential skid hazard, and analyzed with other questionnaire variables. The specific cues were treated separately when they were coded as nonordinal data.

Data on the driver's attitudes regarding prevailing skid hazard at the site included: (1) an assessment of the posted (dry weather) speed limit as being too low, right or too high; (2) an estimate of safe wet driving speed for the site; (3) expressive self-testing data regarding attitudes toward high speed driving, passing while driving at high speeds, proneness to panic in the event of an unexpected skid, and scalar rating of the site as a potential skid hazard. The analysis of driver's expressive self-testing responses appears in Appendix B.

Familiarity with Site. Familiar motorists were more likely to see test signing at Site 1. Those familiar drivers who saw the signing exhibited a greater tendency to properly recall the sign's appearance than did unfamiliar drivers. At Site 2, familiar motorists rated the sign as being more helpful.

The drivers' reactions to potential skid hazard, taken on the basis of their familiarity with the site, were mixed. There seemed to be a trend in that the more familiar Site 2 drivers were less likely to assess the site as a hazard, and the more familiar Site 1 and 3 drivers thought that posted speed limits were too low. However, it was observed that more familiar motorists did exhibit lower speeds at all sites, indicating their increased awareness of the potential hazard. As expected, the more familiar drivers were more likely to report prior skidding experience at the site.

Assessment of Posted Speed Limit. At Site 1, those motorists who said that the posted speed limit should be higher did exhibit higher speeds as they drove through the site. Those motorists interviewed while the pavement was wet were more likely to say the posted limit was too low as it pertained to the dry pavement condition.

At Site 3, those drivers who asserted that the speed limit should be higher were the ones with the most skidding experience at the site.

At both Sites 1 and 3, those motorists wanting the higher speed limits were the more familiar ones and were those less likely to perceive the site as a skid hazard. At all three sites, motorists who thought the posted speed limit was too low also gave higher estimates of safe wet driving speeds.

Estimate of Safe Wet Driving Speed. During periods when more conspicuous signing was displayed, motorists at Sites 1 and 3 gave lower estimates of safe wet weather driving speeds. This effect of experimental signing is compatible with the fact that motorists at Site 2 who did not see the signing gave higher estimates.

At Site 1, older drivers and those whose tires were in better condition gave higher estimates. Tire condition was assessed by both the motorist and the interviewer with highly reliable agreement.

Positive correlations between motorists' driving speeds and estimated safe wet speeds were observed at Sites 1 and 3. At all sites, those drivers who gave higher wet speed estimates also thought the posted speed limit was too low. Higher estimates were given at both sites by male drivers and by those motorists who currently drive the most miles per year.

Assessment of Skid Hazard. Motorists' specific cues of potential hazard are separately treated later in this section. Whether or not the driver considered the site to be a potential hazard is examined here in terms of other questionnaire variables.

At Site 1, fewer motorists assessed the site as a potential skid hazard during times when higher level signing conditions were displayed. However, specific signing characteristics of specificity and conspicuity were not statistically related to those responses. Those motorists in the Site 1 sample who had skidded elsewhere on highway sections than at curves were more likely to rate the site as a hazard.

At Site 2, the familiar motorist was more likely to assess the site as a hazard.

At Sites 1 and 3, those motorists who thought that the posted speed limit should be lower and those who had prior skidding experience at the site were more likely to perceive the site as a potential skid hazard. Older drivers were also more likely to assess the site as potentially hazardous.

Skidding Experience at Site. Motorists who had prior skidding experience at Sites 1 and 3 were those less likely to have properly identified wording on the test signing. They were also more familiar with the site but were less likely to perceive it as potentially skid-hazardous. Site 3 motorists with prior skidding experience at the site were more likely to say that the posted speed limit was too high.

Skidding Experience Elsewhere. Younger drivers interviewed at Sites 1 and 3 indicated more skidding in their overall driving experience. Their skidding experience had been due more to adverse weather conditions than to adverse roadway curvature.

Driving Practice. Annual miles per year driven was taken to be an indicator of the level of current driving practice, and coding was done by grouping motorists according to those who drove less than 5,000, between 5,000 and 10,000, and more than 15,000 miles per year. Adequate samples were obtained in all classifications.

At both Sites 1 and 3, drivers with more practice gave higher estimates of safe wet driving speed, indicated that they would react more calmly in the event of an expected skid, and drove through the curve faster than those with less practice. Male drivers indicated more practice than female drivers at both sites.

At Site 1, drivers who had more driving practice were the older drivers and those with more overall skidding experience during adverse weather conditions.

Expressive Self-Testing. Human expressive self-test traits have been linked to various driving habits. It has been shown that high self-testers drive faster than low self-testers. A treatment of the self-testing responses of the interviewed sample appears as Appendix B of this report. The appendix was authored by Dr. John M. Roberts, Professor of Anthorpology at the University of Pittsburgh, who served as a consultant on this study. Some of his findings based on the Goodman-Kruskal coefficicnt of ordinal association are presented here.

Much research interest has dealt with self-testing responses as a function of sex and age. In the case of the curve respondents, being male was positively associated with driving fast (G = .187), passing (G = .248), and self-reported calmness (G = .427). Youth was positively associated with fast driving (self-reported) (G = .317), passing (.207), and fast driving in the deep curve (G = .192). For these respondents, then, high self-testers tended to be male and young.

One of the variables divided self-reported driving experience into three categories: less than 5,000 miles per year, 5,000-15,000 miles per year, and over 15,000 miles per year. This scale was positively associated with driving fast (G = .151), passing (G = .143), calmness (G = .225) and driving fast in the deep curve (G = .133). It was also associated with maleness (G = 122) and the presence of a stick shift (G = .322). High self-testers drive more.

There was a strong positive association between the owners' estimates of the conditions of their tires and the judged condition of their tires. In other words, drivers knew the condition of their tires and, in a measure, drivers with the better tires were more likely to have seen the test signs (G = .177); they were more likely to have made the appropriate response to the sign (G = .322); they were lcss likely to be driving a vehicle judged defective by the interviewer (G = .793); they were more likely to be driving a car considered showy by the interviewer (G = .296) or neat (G = .236); and, very importantly, they were more likely to be low self-testers on the passing variable (G = .127). It was thought that judgmental accentuation on the part of the low self-testers would produce a response to thc signs, but this hypothesis has not been confirmed by the analysis thus far. Lane placement, however, seems to be a different matter, in that high self-testers on the average drove more to the inside (closer to thc center line) than low self-testers, hence, there was an extremely important interactional effect involving self-testing and the sign conditions. When there is no sign present (sign condition 1), the high self-testers drive more to the outside and low self-testers drive more to the insidc. Thereafter, the high self-testers drive more to the inside and the low self-testers move to the outside.

Age of Driver. Although motorists interviewed at Site 1 (mean age = 39) were older than those at Site 3 (mean age = 36), the difference was not sufficiently great to confound across-site comparisons.

Combined data for Sites 1 and 3 revealed that, of those motorists who saw the experimental signing, the older were more likely to describe the sign as being helpful. Older drivers were more likely to assess the site as a skid hazard. Certain differences in vehicle speeds were observed as a function of driver age. Younger drivers exhibited higher speeds both in advance of and beyond the curves.

Sex of Driver. Motorists' responses based on sex differences did not vary between Sites 1 and 3.

Male drivers who observed test signs were more prone to rate them as being helpful. Males gave higher estimates of safe wet weather driving speeds, while females indicated less prior weather-related skidding. Female drivers expressed a greater tendency to panic in the event of an unexpected skid. It follows that lower vehicle speeds were observed for female motorists both at advance locations and in the curves.

Vehicle Characteristics

That the vehicle plays a major role in skidding accidents is a well known fact. The extent to which certain vehicle characteristics influenced the drivers' attitudes on likelihood of skidding or the speeds they drove was sought by including in the analysis tire condition, vehicle familiarity to driver, and vehicle year. Tire condition was subjectively rated by both the motorist and the interviewer. Vehicle familiarity was determined by asking if the vehicle driven at the time of the interview was the vehicle usually driven by the interviewee.

Tire Condition. At both sites, good agreement was observed between the driver's and the interviewer's assessments of tire condition. Tread depth and evenness of wear were criteria for the interviewer's subjective rating. Observed tire conditions were better on the newer vehicles and on those in better general condition. At Site 1, motorists who rated their tires as being in poorer condition gave lower estimates of safe wet pavement driving speed. However, no significant correlations were found to statistically relate tire condition and speeds actually driven.

Driver Familiarity with Vehicle. Whether or not the vehicle driven at the time of the interview was the vehicle usually driven by the motorist was correlated with other measured variables. Motorists driving unfamiliar vehicles at Sites 1 and 3 were more likely to find test signing helpful. Drivers with unfamiliar vehicles also negotiated the tight curve faster at Site 3 and left the curve faster at both sites. This apparent incongruity may be explained by the fact that many of these motorists were commercial vehicle drivers who were very familiar with the site.

Vehicle Year. The model year of the vehicle driven by the interviewed motorist correlated with a number of variables. Motorists driving new vehicles were more likely to report that they had prior skidding experience on adverse roadway curves. The newer vehicles had better tires and were frequently driven by motorists who were unfamiliar with them.

Vehicle Speeds of Interviewed Motorists

The treatment of speed data which were collected by the Traffic Evaluator System on more than 4000 vehicles and used to examine the effects of various signing and pavement conditions is presented in another section of this report. However, vehicular speeds collected and matched to interview responses for approximately 350 drivers is included in this analysis of questionnaire data. Speed data were gathered at roadswitches located 200 feet in advance of the curve, at the entrance of the curve, in the tight curvature at the exit of the curve, and 200 feet beyond the curve. Experimental signing could be seen by the approaching motorist at the switch pair 200 feet beyond the curve; hence, no control data could be gathered for each subject.

There was little distinction in terms of correlations with other questionnaire variables between speeds at the different locations within each curve; they will therefore be discussed together.

The effects of experimental signing were reflected by observed speeds for interviewed motorists at virtually every curve location at both Sites 1 and 3. Speeds were lower with use of higher level signing conditions. The individual speed-reducing effects of specificity and conspicuity were more difficult to distinguish from the data, as higher level signing was characterized by higher levels of each. However, a specific value of specificity and conspicuity was associated with each signing condition, and correlations were obtained between those values and speeds. At each curve location for both Sites 1 and 3, conspicuity correlated more highly with speeds than did specificity; hence, an indication of its relative effect was obtained.

An examination of vehicle speeds, based on whether or not the motorist observed the displayed test sign, confirmed that signing impacted on speeds. Those motorists who reported that they saw the signing exhibited significantly lower average speeds throughout the entire curve at Site 3 and in the tight portion of the curve at Site 2. Limited available data at Site 2 precluded a determination of curve entry speeds there. Interviewed motorists who saw signs did exhibit substantially lower average speeds at Site 1; however, differences over all signing conditions were not significant at the .05 level.

Although speed reductions were obtained with higher level signing, the conclusion cannot be drawn, on the basis of these differences, that signing is a suitable remediation for slippery highway sections. The magnitude of observed speed differences was not consistently sufficient between sites to favorably impact on braking stopping distances. For example, at Site 1, the difference in mean speeds of interviewed motorists was about 5 mph, while at Site 3 the difference was only 1 mph. A treatment of speeds as they relate to signing conditions for the entire vehicle sample is found in another section of this report.

A significant reduction of interviewed motorists' speeds in the tight curvature was noted between the wet and dry pavement conditions. The entire vehicle population exhibited a similar speed reduction at Site 1.

A number of driver characteristics was observed to correlate with speed differences. Males and younger motorists drove faster at most curve locations within Sites 1 and 3. Those drivers who felt that the Site 1 posted speed limit was too low exhibited higher speeds throughout that curvature. At both Sites 1 and 3, drivers who had higher estimates of safe wet pavement speeds drove faster. Motorists who drove more miles per year consistently averaged higher speeds.

Vehicle characteristics which correlated with observed speeds were extremely limited. Motorists driving vehicles with which they were familiar drove faster in the tight curvature and leaving the curves. Vehicles which were noted by interviewers to be neater and in better condition were driven at higher speeds.

Speeds measured for specific vehicles correlated very highly between locations throughout the curves at all sites. The net effect of this observation is that motorists who drove faster at a given point in the curvature exhibited similar behavior throughout the entire curve.

Motorist's Cue of Potential Skid Hazard

The questionnaire segment pertaining to the motorist's cue that the site might be a potential skid hazard was coded as nonordinal data; hence, its analysis could not be included in that accomplished by Program MISSIN, and it is therefore presented here. Each motorist was asked if he thought the section of highway he had just driven through might be a skid hazard. All "yes" answers were coded with the motorist's observation of what it was that led him to believe the site might be hazardous. Seventy percent of the 305 motorists interviewed at Sites 1 and 3 assessed the sites as hazardous and cited the following cues:

1. Presence of the skid warning sign.
2. Sharp roadway curvature.
3. Appearance of the pavement.
4. Pavement superelevation (banking).
5. Pavement wetness.
6. Known accident history of the site.
7. Driving behavior of other motorists.
8. Other reason.

Table 32 summarizes responses by numbers and percentages of motorists citing each cue according to site, pavement condition, and presence of a skid warning sign. The proportion of drivers citing each cue remained fairly constant over all conditions with about one-third citing sharp curvature, about one-sixth citing driving behavior of other motorists, and almost one-third saying that the site was not a skid hazard. Only 4 out of 305 motorists interviewed cited the skid warning sign as a cue of potential hazard.

For all comparisons, the primary hazard cue was sharp roadway curvature. During wet pavement periods, some motorists' attention was diverted to the fact that the pavement was wet or looked slippery. Three of the four motorists citing the sign as their cue did so during wet pavement conditions. Specific sign conditions cited during wet pavement conditions were: sign condition 2, the international symbolic shield used by itself; condition 4, the shield with flashing lights; and condition 6, flashing lights and the advisory speed limit. The "Slow When Wet" panel was cited during the dry condition.

Table 32

Summary of Motorists' Cues that Site Might Be a Potential Skid Hazard by Number and Percentage of Responses, for Each Site Under Dry Versus Wet Pavement Conditions and With Versus Without Skid Warning Signs (N = 305)

				Wet vs. Dry Pavement						Sign vs. No Sign					
	All Drivers	Site 1 Drivers	Site 3 Drivers	Site 1		Site 3		Site 1 & 3		Site 1		Site 3		Site 1 & 3	
Skid Hazard Cue				Wet	Dry	Wet	Dry	Wet	Dry	Sign	No Sign	Sign	No Sign	Sign	No Sign
Warning Sign	[4] 1	[4] 3	[0] 0	[3] 5	[1] 2	[0] 0	[0] 0	[3] 2	[1] 1	[4] 4	[0] 0	[0] 0	[0] 0	[4] 2	[0] 0
Curvature	[105] 35	[39] 31	[66] 37	[21] 30	[18] 31	[19] 29	[47] 41	[40] 31	[65] 37	[28] 28	[11] 45	[57] 37	[9] 33	[85] 33	[20] 39
Pavement Appearance	[4] 1	[4] 3	[0] 0	[3] 5	[1] 2	[0] 0	[0] 0	[3] 2	[1] 1	[4] 4	[0] 0	[0] 0	[0] 0	[4] 2	[0] 0
Superelevation	[10] 3	[6] 5	[4] 2	[4] 6	[2] 3	[1] 2	[3] 3	[5] 4	[5] 3	[5] 5	[1] 4	[4] 3	[0] 0	[9] 3	[1] 2
Wet Pavement	[5] 2	[5] 4	[0] 0	[5] 8	[0] 0	[0] 0	[0] 0	[5] 4	[0] 0	[5] 5	[0] 0	[0] 0	[0] 0	[5] 2	[0] 0
Accident History	[26] 9	[11] 9	[15] 8	[5] 8	[6] 11	[5] 7	[10] 9	[10] 8	[16] 9	[9] 9	[2] 9	[13] 9	[2] 7	[22] 8	[4] 8
Driver Behavior	[47] 15	[18] 14	[29] 16	[7] 11	[11] 17	[16] 25	[13] 11	[23] 17	[24] 14	[12] 12	[6] 25	[25] 16	[4] 15	[37] 14	[10] 20
Other	[12] 4	[5] 4	[7] 4	[3] 5	[2] 3	[5] 7	[2] 2	[8] 6	[4] 2	[4] 4	[1] 4	[6] 4	[1] 4	[10] 4	[2] 4
Not Hazardous	[92] 30	[33] 26	[59] 33	[15] 22	[18] 31	[19] 30	[40] 34	[34] 26	[53] 33	[30] 29	[3] 13	[48] 31	[11] 41	[78] 30	[14] 27
Total	[305] 100	[125] 100	[180] 100	[66] 100	[59] 100	[65] 100	[115] 100	[131] 100	[174] 100	[101] 100	[24] 100	[153] 100	[27] 100	[254] 100	[51] 100

Contrasting cue responses between signing and no signing conditions reveals minor differences. As was mentioned earlier, significantly fewer motorists assessed one site (Site 1) as a potential skid hazard while test signs were displayed. The table indicates that, without the presence of signing, a larger percentage of motorists cited the hazard cue as being roadway curvature or other driver's behavior, and all but 13 percent cited some cue of skid hazard. With experimental signing present, more diverse hazard cues were cited, but significantly more motorists reported no hazard. It is possible that the emergence of more diverse cues during the presence of signing indicates that motorists may have been more aware of various possible hazards. However, the concurrent increase in motorists' assessments that no hazard exists could indicate that the site is thought to be safer with the presence of signing. In either event, the effect was not repeated at Site 3; hence, no conclusive evidence was found to indicate that the signing had any impact on motorist's perception of skid hazard.

Overview of Rain Site Questionnaire Findings

Questionnaire results were highly revealing in terms of motorists' responses to the test signing. Vehicle speeds of interviewed motorists demonstrated that motorists who saw signing slowed down. Maximum speed decreases were observed at the most hazardous portions of curvature. Greater slowing was observed during use of higher level signing with sign conspicuity having a greater impact than specificity. A driver's recognition of sign message versus appearance alone did not impact on his speed. The more familiar motorists were more likely to see the test signs, and those with greater driving practice were more likely to read them. It was shown that the experimental skid hazard warning signs have a marginal effect on motorists' perception of skid hazard.

Certain driver characteristics were linked to general perception of skid hazard. Younger drivers and those with prior skidding experience were seen to be more prone to assess test curves as potential skid hazards. Motorists who drive more miles per year exhibited higher speeds throughout the sites, but they were divided in their assessments of skidding potential. Female drivers were seen to be generally more sensitive to wet weather driving hazards as they gave lower estimates of safe wet pavement speeds, predominantly indicated that skid warning signs were helpful, and indicated a tendency to panic in the event of an unexpected skid. It follows that female drivers reported less prior weather-related skidding than male drivers.

Questionnaire Analysis – Icy Bridge Sites

Interviewing of motorists was conducted on cold February mornings during times when there was the maximum probability of preferential bridge icing. Data were collected during two hours of predawn darkness and two hours of daylight. The weather was clear with temperatures ranging from 17° to 32° F. Light frost occurred during two of four data collection days; however, the pavement remained virtually dry. Data could not be gathered during extreme icing because of danger associated with stopping fast moving vehicles to be interviewed.

Speed data were unobtrusively collected on two bridge approaches: one long and one short sight-distance. Speeds were gathered on each approach at 1,200 and 600 feet in advance of the bridge, at the bridge entrance point, and 150 feet onto the bridge.

An interviewing strategy was adopted which permitted certain driver characteristic data to be obtained prior to the driver's knowledge that the study related to the potential icy bridge hazard. After a brief introduction to the motorist advising that a safety study was being conducted, general questions were asked to derive the driver's familiarity with the site and the level of his driving practice. More specific questions were then asked regarding his skidding experience at the bridge, his cue that the bridge might be icy, and his observation of an icy bridge warning sign. Motorists were asked to fill out an expressive self-testing questionnaire similar to that used in the rain study. The form was accompanied by a disclaimer that the answers were to be used only for research purposes. Questions pertained to the driver's feelings about driving fast on two-lane rural roads, about passing while driving at high speeds, about proneness to calm or to panic in the event of an unexpected skid, and to the driver's scalar rating of the bridge as being dangerous as a skid hazard.

Questionnaire information and matched vehicle speed data were coded onto punched cards and classified as 38 variables. Relationships between all variables were derived using Program MISSIN (described earlier).

Samples of the interview forms used are found in Appendix A, and Appendix C which is a separate volume provides a complete listing of Program MISSIN output.

Examination of motorists' responses to the potential icy bridge hazard and the effect of experimental signing on those responses is included in the discussion which follows. A matrix depicting 23 relevant variables and a diagrammatic representation of significance obtained between each pair is given as Figure 40. Variables are assigned to the following categories: signing, ambient condition,

	Activation	Location	Position of Activated Signing	Darkness vs. Daylight	Presence of Frost	Sign Observation	Observation of Both Signs	Recognition of Appearance	Recognition of Wording	Rated Sign as Helpful	Familiarity with Site	Skidding Experience on Bridge	Driving Practice	Knowledge of Bridge Maintenance	Assessment of Possible Icing	Age	Sex	1200' Advance of Bridge	600' Advance of Bridge	Bridge Entry	On Bridge	Long vs. Short Sight-Distance
Signing																						
Activation						●	●	●	●	●					●				○	●	●	
Location																						
Position of Activated Signing						●													●	●	●	
Ambient Condition																						
Darkness vs. Daylight						●	●	●	●		●				●			○	○	●	●	
Presence of Frost															●				●	●	●	
Driver Response to Signing																						
Sign Observation	●		●	●							●				●				●	●	●	
Observation of Both Signs	●		●	●										●					●	●	●	●
Recognition of Appearance	●			●					●	●									●	●	●	
Recognition of Wording	●			●				●		●						○				●	●	
Rated Sign as Helpful	●							●	●										●	●	●	●
Driver Characteristics																						
Familiarity with Site				●		●						●								●	●	
Skidding Experience on Bridge											●											
Driving Practice														●		●	●	●	●	●	●	
Knowledge of Bridge Maintenance							●						●									
Assessment of Possible Icing	●			●	●	●											○	○	●	●	●	
Age									○				●					○	●	●	●	
Sex													●		○							
Vehicle Speeds																						
1200' Advance of Bridge				○									●		○	○						●
600' Advance of Bridge	○		●	○	●	●	●	●		●			●		●	●						●
Bridge Entry	●		●	●	●	●	●	●	●	●			●		●	●						●
On Bridge	●		●	●	●	●	●	●	●	●			●		●	●						●
Approach Geometry																						
Long vs. Short Sight-Distance							●			●								●	●	●	●	

Figure 40. Matrix of 23 relevant icy bridge warning sign questionnaire variables depicting level of significance obtained between each pair.

driver responses to signing, general driver characteristics, observed vehicle speeds and approach geometry. Dots in the matrix cells represent significant correlations, at the .05 level or better, obtained between the corresponding variable pairs. Black dots indicate relationships obtained for two or more sites; white dots indicate the relationship at a single site.

Signing Variables

Activated and nonactivated signs were tested at each site for two approach locations: at the bridge and 1,000 feet in advance of the bridge. The effects of each type, location, and combination were studied. Since activated signing was found to have a greater impact on motorists, specific attention was given to the effect of its location.

Activation. The advantages of activated over nonactivated signing were seen through correlations obtained among numerous variable-paired comparisons. At both sites, the use of activated signing increased the tendency for motorists to: (1) see the signing, (2) notice both signs when two were displayed, and (3) properly identify both the sign's appearance and wording. Motorists were more prone to acknowledge the possibility of bridge icing while at least one activated sign was displayed. As the data were collected during periods of virtually dry pavements, an inference from this last finding is that motorists were more aware of icing possibilities when activated signing served as a reminder.

Use of activated signing produced lower speeds than nonactivated signing at the bridge entry point and on the bridge itself at both sites. It follows that speed reductions all through the approaches were greater with the use of activated signing. A discussion of signing effects on speed data for both interviewed and noninterviewed motorists appears elsewhere in this report.

Location. A comparison between those signing schemes incorporating advance signs versus those incorporating bridge signs showed no significant differences with respect to any questionnaire variables.

Location of Activated Signing. In light of the favorable impact on motorists observed with activated signing, a comparison was made among signing schemes utilizing activated signs at the bridge and advance for both locations. A significant increase was observed in the proportion of motorists who saw signing when the activated signing was placed at the bridge rather than at the advance location. The percentage of those motorists who correctly identified sign appearance and wording ranged from 70 to 100 percent of those observing the sign; the percentage was unaffected by sign location.

Activated signing, when located at the bridge as opposed to the advance location, was significantly more likely to result in reduced speeds of interviewed motorists at the 600-foot advance location, bridge entry point, and on the bridge. The use of activated signing at both the bridge and advance locations increased the proportion of motorists who saw both signs and properly identified the signs' appearance and wording during hours of darkness. Further speed decreases were observed for motorists entering and on the bridge with the use of two activated signs.

Table 33 provides the percentages of interviewed motorists who observed signing for each experimental condition. Of those motorists, the percentage who properly identified signing appearance and message is also given. Best results were obtained with the activated bridge-located sign and with activated signing at both locations. Results are further explained, with a discussion of appropriate variables, later in this section.

Ambient Condition

Data were collected during winter months at times of day when there existed the maximum probability for preferential icing. Observations commenced two hours before sunrise and continued for two hours of daylight. Temperatures ranged from 17°F to 32°F. It was not possible to interview motorists during periods of extreme icing.

Two ambient condition comparisons revealed an impact on driver responses to icy bridge warning signs. Effects of daylight versus darkness and dry weather versus light frost were seen to result in some notable differences.

Darkness vs. Daylight. During hours of darkness, a significantly higher proportion of interviewed motorists reported seeing the signs and properly identified their appearance and wording. Increased conspicuity of activated signing due to darkness was undoubtedly responsible for the difference, as no significant change in the nonactivated sign observation rate was noted.

Table 34 contrasts motorists' observations of the signing between conditions of daylight and darkness. Weighted averages for motorists seeing the sign during darkness and daylight are 56 percent and 30 percent respectively. The combined effect of darkness and activation is evident from the fact that observation rates for nonactivated signing are less variable: 29 percent during daylight hours and 21 percent for darkness.

Table 33

Percentages of Interviewed Motorists (N = 168) Who Observed Experimental Signing and Properly Identified Its Appearance and Wording by Signing Condition

	Signing Condition							
Advance	No Sign	BRIDGE ICY AHEAD	BRIDGE ICY AHEAD	WATCH FOR ICE ON BRIDGE	No Sign	WATCH FOR ICE ON BRIDGE	WATCH FOR ICE ON BRIDGE	BRIDGE ICY AHEAD
Bridge	WATCH FOR ICE	WATCH FOR ICE	ICE ON BRIDGE WHEN FLASHING	No Sign	ICE ON BRIDGE WHEN FLASHING	ICE ON BRIDGE WHEN FLASHING	WATCH FOR ICE	No Sign
	n=23	n=23	n=24	n=23	n=10	n=25	n=25	n=15
Observed Signing	17	37	54	26	60	72	32	20
Recalled Appearance	0	92	85	67	83	94	38	67
Recalled Wording	33	85	85	67	83	89	13	67

Table 34

Percentages of Interviewed Motorists (N = 168) Who Observed Experimental Signing for Conditions of Daylight Versus Darkness

	Signing Condition								
Advance	No Sign	BRIDGE ICY AHEAD	BRIDGE ICY AHEAD	WATCH FOR ICE ON BRIDGE	No Sign	WATCH FOR ICE ON BRIDGE	WATCH FOR ICE ON BRIDGE	BRIDGE ICY AHEAD	
Bridge	WATCH FOR ICE	WATCH FOR ICE	ICE ON BRIDGE WHEN FLASHING	No Sign	ICE ON BRIDGE WHEN FLASHING	ICE ON BRIDGE WHEN FLASHING	WATCH FOR ICE	No Sign	Weighted Average
Daylight	n=12 25	n=9 22	n=14 21	n=15 27	No Data	n=10 70	n=15 33	n=15 20	30
Darkness	n=11 9	n=14 79	n=10 100	n=8 25	n=10 60	n=15 73	n=10 30	No Data	56

A greater proportion of familiar motorists appeared in the sample during hours of darkness. More motorists indicated that they thought the bridge might be icy during periods of darkness.

Another effect of darkness was that lower speeds were observed at both sites prior to daybreak. Speeds of interviewed motorists as they entered the bridge and while on the bridge were lower at both sites, and speeds throughout the approach were lower for the long sight-distance case.

Presence of Frost. During periods of light frost, more motorists acknowledged the possibility of ice formation on the bridge. Lower speeds were measured at the 600-foot advance, bridge entry, and on bridge locations during periods of frost. The motorists' cue of frost was predominantly its accumulation on their windshields.

Driver Responses to Signing

Variables examined are motorists' observation of signing, observation of both signs when two were displayed, proper identification of sign wording and appearance, and rating of the signing as helpful. Vehicle speeds are treated separately.

Sign Observation. Significant increases in the proportion of motorists observing signs were noted with the use of activated as opposed to nonactivated signing. Improved responses were obtained when the activated sign was located at the bridge rather than at the advance location. A higher proportion of motorists noticed the signing during hours of darkness.

Motorists who were more familiar with the sites were more prone to notice signing. Those motorists who noticed the signing were more likely to acknowledge the possibility of ice being on the bridge.

Greater speed reductions throughout the array and lower speeds both on the approach and on the bridge itself were observed for drivers at both sites who had observed the signing.

Motorists' observation of signing by specific sign condition is shown in Table 33. Highest observation rates were obtained for the "Ice On Bridge - When Flashing" sign at the bridge both with and without the advance nonactivated "Watch For Icc On Bridge" sign. The activated "Bridge Icy Ahead" sign used at the advance location did not produce an improvement except during hours of darkness (see Table 34).

Observation of Both Signs. For signing conditions comprised of two signs, data were maintained on which of the signs were observed by motorists. Motorists were more likely to see both signs for conditions when at least one activated sign was in use. Both signs were more often seen during hours of darkness and periods of frost. Drivers who thought that the bridge was not regularly sanded were more prone to see both signs. Motorists seeing both signs were more likely to exhibit greater speed reductions than those seeing one sign. Speed reductions throughout the entire approach for those motorists seeing both signs were greater on the long sight-distance approach. Both signs were observed more frequently on the short sight-distance approach.

Proper Identification of Sign Appearance. A significantly higher proportion of motorists properly identified activated over nonactivated signing with improved performance during hours of darkness. Drivers who properly identified signing appearance were more likely to identify its wording and to rate the sign as being helpful. Lower approach and bridge speeds were observed for those motorists.

Table 33 indicates percentages of interviewed motorists who properly identified sign appearance by signing condition. Average percentages, weighted by sample size, of drivers identifying appearance of activated and nonactivated signing schemes are 86 percent and 35 percent, respectively. The weighted average percentage of motorists' identifying advance- versus bridge location-activated signing are 83 percent and 87 percent, respectively. This indicates a nonsignificant difference, although it should be kept in mind that more drivers saw the bridge-activated signing.

Proper Identification of Sign Wording. Motorists were most likely to properly identify the wording of activated signing, and a higher proportion of correct responses was obtained during hours of darkness. It stands to reason that drivers who properly identified sign appearance were more prone to correctly identify the wording and to rate the sign as being helpful. At one site, wording was more often correctly identified by older drivers. The mean age for drivers at that site was 41.

Again, referring to Table 33, percentages of drivers correctly identifying wording are shown by sign condition. The weighted average for activated signing is 83 percent compared to 37 percent for nonactivated. As was the case with sign appearance, the bridge-activated signing elicited a slightly better response with 86 percent than did the advance with 81 percent.

Rating Signing as Helpful. As indicated above, motorists who properly identified sign wording and appearance were more prone to rate the sign as being helpful. Motorists on the short sight-distance approach, where the bridge was not visible as the signing came into view, were more likely to assess the signing as helpful.

Drivers who rated the signing as being helpful exhibited lower speeds on the approach and the bridge.

Driver Characteristics

Relationships between selected driver characteristics and signing responses were examined to provide a better human factors understanding of icy bridge warning signing requirements.

Driver factors examined are site familiarity, prior skidding experience on the bridge, annual miles driven, opinion regarding routine icy bridge maintenance operations at the site, assessment of the probability that the bridge might be icy, age, and sex.

Familiarity with Site. A greater proportion of familiar motorists was observed at both sites during hours of darkness due to the occurrence of some commuter traffic. Familiar motorists were more likely to observe the experimental signing; however, their recognition of specific sign characteristics did not differ from those of unfamiliar drivers. As expected, familiar motorists were more prone to report prior skidding experience on the bridge.

Familiar motorists drove more slowly as they reached the bridge and while on the bridge than did unfamiliar motorists.

Prior Skidding Experience on Bridge. Motorists who reported prior skidding experience on the bridge exhibited greater speed reductions as they approached the bridge. A speed reduction is defined here as the difference between the greater speed recorded on either of the advance traps and the lesser of the speeds recorded at the bridge entry or on the bridge. As was mentioned above, this driver sample was comprised of the more familiar motorists.

Knowledge of Bridge Maintenance. Motorists were asked if they knew whether or not the bridge was salted or sanded each time when it was icy. The intent of the question was to ascertain the impact on the speeds of those drivers who were confident of maintenance activity; however, no speed differences were observed. Opinion was generally divided among all drivers. Those motorists with more driving practice felt that the maintenance was not regularly performed. No difference in opinion was observed as a function of site familiarity. Drivers who felt that the bridge would probably not be sanded were more prone to observe both signs when two were displayed.

Driving Practice. The most significant finding based on driving practice, measured by miles per year currently driven, was that higher speeds were observed for those with more driving practice. As mentioned above, motorists with more practice were less likely to feel that the bridge was salted or sanded regularly when it was icy. Interviewed motorists who drove more miles per year were the younger and the male drivers.

Assessment of Possible Icing. As interviewing was conducted during periods of marginal occurrences of actual bridge icing, motorists were asked if they thought the bridge might be icy. Responses correlated with a number of variables.

More motorists acknowledged the possibility of icing during periods when activated signing was being used. Increased responses were noted during periods when two activated signs were displayed. As indicated earlier, the inference from this finding is that motorists were made more aware of the icing probability as a result of the cue afforded by the signing. However, it should be noted that motorists also responded to actual ambient conditions since more observations were noted during predawn hours during the actual presence of frost.

Those drivers who indicated the possibility of bridge icing did exhibit lower speeds throughout the array of data collection points. The most notable speed reductions at both sites occurred at the bridge entry location – the critical slowing point for a motorist concerned about bridge icing. The second highest speed reduction occurred on the bridge, confirming the motorists' concern about bridge icing.

That the signing was largely responsible for speed reductions of those motorists who suspected bridge icing is somewhat evident from the locations of the speed decreases as well as from the sign observation responses. Speed reductions were not significant at the most advanced tapeswitch pair on the short sight-distance approach where the bridge-located warning sign was not visible.

Age. The mean age for motorists at both sites was 42. Younger drivers at both sites were observed to drive faster and to have less driving practice. The only location at which no age-related speed difference was noted was the 1,200-foot advance location on the short sight-distance approach. Another finding which confirms that younger drivers have less regard for the icy bridge hazard is that they were significantly less likely to recognize sign wording at one site.

Sex. Two observations were made regarding differences according to sex: 1) At both sites, interviewed females drove significantly fewer miles per year; and 2) at one site, females were more likely to acknowledge the possibility that the bridge was icy.

Vehicle Speeds of Interviewed Motorists

Speed data were recorded for each site at four roadswitch locations: 1,200 feet in advance of the bridge, 600 feet in advance, at the bridge entrance point, and 150 feet beyond the point at which the motorist entered the bridge. Notable similarities were found between speed correlations for the first two points; however, those for the latter two were identical. Therefore, they will be grouped accordingly for purposes of discussion. Speeds discussed here are those recorded for interviewed motorists; speeds for the entire observed population are discussed elsewhere in this report.

Advance Speeds. At the 1,200-foot advance speed trap, significantly lower speeds were recorded for motorists with less driving practice, for drivers who perceived the possibility of the bridge's being icy, and for older drivers at one site.

At the 600-foot advance location, more slowing was observed. Lower speeds were recorded on the long sight-distance approach for signing conditions employing activated signs and on both approaches when the activated signs were located at the bridge. Reduced speeds were obtained at this point during periods of frost, regardless of signing.

Motorists who saw and properly identified the warning sign appearance slowed down at this point. Higher speeds were recorded for motorists who saw the signs but felt that they were not helpful. It is noteworthy that no speed differences were recorded at the 600-foot advance location on the basis of motorists' familiarity with the site.

Bridge Entrance and on Bridge. Speeds at these two locations are the most critical and comprised the greatest number of observed differences. Lower average speeds were exhibited by motorists during the use of activated signing. Greater speed reductions were recorded when active signing was used at the bridge as opposed to the advance location. The use of activated signs at both locations produced further speed reductions.

Average speeds were observed to be lower during hours of darkness and periods of frost. Lower speeds were recorded for motorists who saw the experimental signing (either one or two signs), properly identified the sign's appearance and wording, and rated the sign as being helpful. Driver characteristics associated with lower speeds were observed to be: greater site familiarity, more miles per year driven, perception of possible bridge icing, and greater age.

An interesting observation regarding the location at which slowing occurred is that motorists who read the sign correctly waited until arriving at the bridge to slow down. Drivers who recognized the appearance but not the wording, slowed earlier.

It should be emphasized here that the speed data discussed above were limited to data gathered for interviewed motorists who comprised a small percentage of the total driver sample from whom speed data were obtained. Directions rather than magnitudes of differences were discussed, since the value of speed changes for specific sign conditions were covered in the preceeding section of this report.

Approach Geometry

The sites were similar in all respects with the exception that one approach exhibited a long sight-distance where the bridge was visible ahead of the advance sign location; the other site was characterized by short sight-distance geometry, permitting each sign to come into the approaching motorist's field of view prior to his seeing the bridge. Hence, the effects of short- versus long-sight distances are examined.

Short versus Long Sight-Distance. Because geometry on the short sight-distance is more conducive to motorists' observation of signing, Table C is provided to show percentages of motorists observing each sign condition by site. No significant difference in sign observation is noted: average percentages (weighted by subject number) for the long and short sight-distance approaches are 40 percent and 46 percent respectively. The impact on sigh observation of activated sign conspicuity by daylight versus darkness did override the effect of long versus short sight-distance. The only impact on sign observation was that, for signing schemes comprised of two signs, motorists were significantly more likely to see both signs on the short sight-distance approach.

Lower speeds were observed on the short sight-distance approach due to the roadway geometry.

Table 35

Percentages of Interviewed Motorists (N = 168) Who Observed Experimental Signing by Approach Geometry

	Signing Condition								
Advance	No Sign	BRIDGE ICY AHEAD	BRIDGE ICY AHEAD	WATCH FOR ICE ON BRIDGE	No Sign	WATCH FOR ICE ON BRIDGE	WATCH FOR ICE ON BRIDGE	BRIDGE ICY AHEAD	
Bridge	WATCH FOR ICE	WATCH FOR ICE	ICE ON BRIDGE (WHEN FLASHING)	No Sign	ICE ON BRIDGE (WHEN FLASHING)	ICE ON BRIDGE (WHEN FLASHING)	WATCH FOR ICE	No Sign	Weighted Average
Long Sight-Distance Approach	n=11 9	n=14 79	n=14 21	n=15 27	n=10 60	n=15 73	n=15 33	n=15 20	40
Short Sight-Distance Approach	n=12 25	n=9 22	n=10 100	n=8 25	No Data	n=10 70	n=10 30	No Data	46

Overview of Icy Bridge Site Questionnaire Findings

Questionnaire results were most enlightening regarding the effects of test signing on motorists' responses. Activated signing elicited significantly higher responses than did non-activated signing in terms of drivers' observing, recognizing, and reading test signs. Interviewed motorists who had observed the signing exhibited greater speed reductions on the bridge and its approach. Better overall responses were elicited by activated signing located at the bridge rather than 1,000 feet in advance. Activated warning signs were apparently effective as a hazard cue since more drivers acknowledged the possibility of bridge icing while activated signs were displayed, regardless of the actual presence of frost.

CONCLUSIONS

Summary and Findings

A field study investigated the driver's general awareness and his response to warning signs for two types of skidding hazard: wetted pavements subjected to high driver frictional demands and highway bridges during periods of potential icing. Detailed vehicle performance data were collected, and speeds were used as the primary indication of hazard awareness and sign response. Driver interviewing was used to establish the motorist's cognizance of the hazard and his observation of the warning sign. Selected driver characteristics were obtained during the interview and were compared to hazard responses. The study conducted for each hazard type is summarized separately.

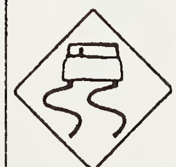
Wet Pavements

Three curved highway sections were treated using five experimental signing conditions. Comparisons between all signs and the "no sign" condition were made for wet and dry pavements. Normative driving behavior data were used to resolve time-of-day speed variations. Experimental signing conditions were comprised of variations to the "Slippery When Wet" symbolic sign, ranging from its use by itself through increasing levels of specificity and conspicuity, to its use with flashing beacons and an advisory speed limit.

Specific vehicle performance measures examined were speeds and mean acceleration/deceleration. The primary measure of signing effectiveness was mean speeds at critical curve locations. The highest quartile speed group (fastest 25 percent) of vehicles arriving at the advance speed trap was selected as the target sample. Table 11 (also shown on page 91) lists mean speed differences between wet pavement and normative driving for the target sample, and this is illustrative of effects observed at all sites. Little or no benefit was derived from use of the symbolic sign alone. Increasingly improved responses were obtained for higher levels of conspicuity and specificity. Differences in "no sign" mean speeds between the two days result from a higher proportion of familiar motorists in the sample on the second day. No significant sign-related changes were observed in mean acceleration/deceleration rates as motorists initiated speed reductions prior to reaching the curve, in cases of effective signing.

Table 11

Differences in Highest Quartile Speeds Between Normal, No Signing, Dry Pavement Conditions and Experimental Signing, Wet Pavement Conditions at Site 1

	November 5, 1973				November 27, 1973		
	No Sign				No Sign		
200′ Advance	1.8	.6	1.6	4.8	2.3	5.7	7.1
Enter Curve	1.2	1.4	3.2	4.9	3.1	6.8	7.8
Tight Curvature	1.3	2.3	3.7	4.3	3.1	5.4	6.4
Leave Curve	2.7	1.9	4.6	4.5	3.0	5.9	7.1

Generally consistent effects of experimental signing to warn of potential skidding hazards were observed at three sites. With one exception, there was no evidence to support the use of low conspicuity signing. At one site, the use of low conspicuity, moderate specificity signing ("Slow When Wet") elicited significantly reduced motorists' speeds at the curve entry point and in the tight curvature during wet pavement conditions. However, this observation was not repeated at other sites.

Sufficient site characterization permitted a comparison of observed motorists' speeds with the critical wet pavement speed based on the site geometry and pavement characteristics. All high conspicuity experimental signing did result in virtually all motorists driving below that speed during wet pavement conditions. Substantial speed reductions obtained at the remaining sites with high conspicuity signing displayed during wet pavement conditions did corroborate that the flashing beacons were effective in warning motorists of the potential hazard.

Questionnaire results were revealing in terms of motorists' responses to experimental signing. Vehicle speeds of interviewed motorists demonstrated that motorists who saw signing slowed down more than those who did not. Maximum speed decreases were observed at the most hazardous portions of curvature. Greater slowing was observed during use of higher level signing with sign conspicuity having a greater impact than specificity. A driver's recognition of sign message versus appearance alone did not impact on his speed. The more familiar motorists were more likely to see the signs, and those with greater driving practice were more likely to read them. It was shown that the experimental skid hazard warning signs have a marginal effect on motorists' verbal assessment of the site as being a skid hazard.

Certain driver characteristics were linked to general perception of skid hazard. Younger drivers and those with prior skidding experience were seen to be more prone to assess test curves as potential skid hazards. Motorists who drive more miles per year exhibited higher speeds throughout the sites, but they were divided in their assessments of skidding potential. Female drivers were seen to be generally more sensitive to wet weather driving hazards as they gave lower estimates of safe wet pavement speeds, predominantly indicated that skid warning signs were helpful, and indicated a tendency to panic in the event of an unexpected skid. It follows that female drivers reported less prior weather-related skidding than male drivers.

Icy Bridges

An examination of eight experimental signing combinations comprised of activated, non-activated, advance- and bridge-located signs was conducted at two bridge approaches. In all cases, activated signing elicited greater speed reductions than did nonactivated signing. Of the nonactivated signing observed, the advance "Watch for Ice on Bridge" sign provided better results than the "Watch for Ice" sign at the bridge. Undoubtedly, the bridge competed for driver attention and negated any effect of the latter sign.

Improved responses to signing were obtained at the short sight-distance bridge approach. Better overall responses were obtained during the hours of darkness.

The sign condition eliciting the maximum speed-reducing effect consisted of activated signing at both advance and bridge locations during hours of darkness. Bridge-located activated signs elicited larger speed reductions than did advance-located activated signs during both conditions of daylight and darkness.

Motorist interviewing was used to expand and clarify responses to icy bridge warning signs. It was found that activated signing elicited significantly higher responses than did nonactivated signing in terms of drivers' observing, recognizing, and reading test signs. Interviewed motorists who had observed the signing exhibited greater speed reductions on the bridge and its approach. Better overall responses were elicited by activated signing located at the bridge rather than 1,000 feet in advance. Activated warning signs were apparently effective as a hazard cue since more drivers acknowledged the possibility of bridge icing while activated signs were displayed, regardless of the actual presence of frost.

Recommendations

Wet Pavement Warning

Significant speed reductions observed at critical curve locations during conditions of wet pavements were shown to result from warning signs incorporating flashing beacons. This result must be regarded as sufficiently promising to suggest their operational use. It is to be emphasized, however, that responses were elicited from experimental signing installed immediately prior to rainfall occurrence rather than from permanent installations to which motorists had become acclimated. Further, it is to be recalled that the literature has shown poor driver responses to continuously displayed warning devices. Hence, any recommendation for similar warning device usage must emphasize the need for activation of the flashing beacons at the onset of rainfall.

The recommendation for specific wording employed as part of the device stems not only from this study's field observations. Advisory speed limit panels generally showed slight, although insignificant, improvements over other conspicuous signing used in the field evaluation. However, reviewed literature pertaining to accident liability has shown use of the advisory speed limit sign as being considered prudent on the part of highway agencies (Oliver, 1974), and favorable accident rate effects have been shown to result from the use of advisory speed limits on curve warning signs (Hammer, 1968). A documented technique to determine applicable wet weather speed limits is available (Weaver, 1973).

The recommendation follows that activated warning signing be used as a skidding accident reducing countermeasure. Specifically recommended signing is that designated in the *1971 Manual on Uniform Traffic Control Devices* as the Slippery When Wet sign (W8-5) in conjunction with the Advisory Speed Plate (W13-1) and *rainfall activated* hazard identification beacons (similar to that called out in Section 4E of the MUTCD). The activation device should insure that beacon flashing will terminate as the pavement becomes dry. Sign location with respect to the curve should be in accordance with current practice.

Icy Bridge Warning

Two sign conditions employing activated signing are recommended for further study based on field observation. The sign scheme eliciting the best response was an activated "Bridge Icy Ahead" sign 1,000 feet in advance of the bridge in concert with a "Ice on Bridge When Flashing" sign incorporating activated hazard identification beacons. An effective, less costly alternative was observed when the nonactivated "Watch for Ice on Bridge" was substituted at the 1,000-foot advance location. The effectiveness of the signing would be dependent on a reliable ice detection system for its activation.

Future Research Needs

The preceding recommendations for warning sign usage were based solely on behavioral observations. However, the primary objective of the signing is to reduce accidents. There does exist the obvious need for accident study prior to consideration of standardizing recommended signing.

Although this field evaluation has suggested one signing scheme as a promising remediation for wet weather accidents on curved highway sections, there are inherent disadvantages associated with its use. Warning signs have traditionally demonstrated questionable accident reducing capability. In addition, the recommended activated warning sign would be costly. Activation reliability creates new problems. Clearly, other countermeasures need to be developed.

This study has demonstrated that signing does not suffice as the motorist's primary cue of potential skid hazard. About one percent of the interviewed motorists cited the experimental sign as their cue of possible hazard. Other environmental components of roadway geometry, surface appearance, and prevailing ambient conditions are more apt to be sensed by the driver. Therefore, a more in-depth human factors study, incorporating sensitive measurement techniques such as driver eye movement photography, is needed to determine the appropriate sensory inputs used in certain skid prone driving situations. With such information, it is possible that more effective, economic, and politically feasible countermeasures can be developed to alert the driver to the highway site with high skid accident potential.

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APPENDIX A

SAMPLE QUESTIONNAIRE FORMS

Sample Questionnaire Forms

Sites 1, 2, and 3

SKID Questionnaire

Date ______________________ Site ___________________________ Number ________________________________

INTRODUCTION

Thanks for stopping. We're making a study for the U.S. Department of Transportation and would appreciate a few minutes of your time to help make highways safer.

INTERVIEWER'S QUESTIONS

1. Could you tell me about how often you drive by here?

   _____first time _______weekly _________more often

   _____ monthly _______almost daily

2. About how many miles per year do you drive?

   _____less than 5,000; ________5-15,000;

   _____more than 15,000.

3. Is this the car you usually drive?

   _____Yes _______No

4. In what general condition are your times?

   _____good _____ fair ______poor _______don't know

   Comments: ____

   ____

   ____

5. The speed limit here is _____ mph. Do you think this is a good speed limit when the road is dry?

   Yes_____ No ______ Should it be slower? _______ faster? _______

6. What do you think the speed limit should be when the road is wet?

   _____mph

7. Have you ever had any trouble with slippery pavement or skidding in the curve you just drove through?

   _____Yes _____No

   Was it wet ______ dry ______ icy ______

8. Have you ever slipped or skidded on pavement anywhere else?

   _____Yes _____No

   Was it wet______ curve ________

   dry______ straight________

   icy______

9. Do you have any reason to believe the road at this (curve, ramp) might be a skid hazard?

   _____Yes _____No

   Why?

   _____saw a sign (go to #11) _______slow driver ahead

   _____sharp curvature _______pavement appearance

   _____vehicle started to slide _______it is raining

   _____others have skidded here _______motorists drive too fast here

   _____other*

* ____

____

INTERVIEWER'S QUESTIONS (Continued)

10. Did you see a skid warning sign?

    _____Yes _____No (Stop verbal interview)

    (Omit unless motorists saw sign)

11. What did the sign say?

    What did the sign look like?

    Was the sign helpful?

    _____Yes _____No

    How?

INTERVIEWER

Give motorists the fill-in portion and complete the following:

Vehicle ______________________________

Color ______________________________

Year ______________________________

Estimate Driver's Age ____________________

Sex ____________________

Weather ______________________________

Time ______________________________

Obvious Vehicle Defects ______________________________

____

____

____

____

____

____

Condition of tires ______________________________

Rate vehicle appearance in terms of its being ornate or showy:

Low ☐ Intermediate ☐ High ☐

Rate vehicle appearance in terms of neatness.

Low ☐ Intermediate ☐ High ☐

Stick Shift? No ☐ Yes ☐ (Four-on-Floor)

Motorist's Fill-In Questions

"Please provide thoughtful consideration of these few questions. They are asked for research purposes only, and your answers will remain in strictest confidence."

1. What is your occupation?

____

PLEASE CIRCLE THE NUMBER WHICH BEST DESCRIBES YOUR FEELINGS.

2. How well do you like to drive an automobile at relatively high speeds on two-lane roads?

Unhappy –3 –2 –1 0 +1 +2 +3 Happy

3. How well do you like to pass cars while driving at relatively high speeds on two-lane roads?

Unhappy –3 –2 –1 0 +1 +2 +3 Happy

4. Everyone has experienced skidding on wet pavements. What would be your reaction in the event of such a sudden and unexpected skid?

Panic –3 –2 –1 0 +1 +2 +3 Calm

5. How dangerous do you think this curve you just drove through is under these weather conditions?

Dangerous –3 –2 –1 0 +1 +2 +3 Safe

THANK YOU FOR YOUR TIME.

Sample Questionnaire Forms

Sites 4 and 5

INTRODUCTION

Thanks for stopping. We're making a study for the U.S. Department of Transportation and would appreciate a few minutes of your time to help make highways safer.

INTERVIEWER'S QUESTIONS

1. Could you tell me about how often you drive by here?

   ______ first time ______ monthly ______ weekly ______ almost daily ______ more often

2. About how many miles per year do you drive?

   ______ less than 5,000 ______ 5-15,000 ______ more than 15,000

3. Is this the car you usually drive?

   ______ Yes ______ No

4. The speed limit here is 50 mph. Do you think this is a good speed limit when the bridge you just drove over is dry?

   ______ Yes ______ No Should it be slower? ______ Should it be faster? ______

5. What do you think the speed limit should be when there is a possibility of icy conditions?

   ______ mph

6. Have you ever had any trouble with slipping or skidding on the bridge you just drove over?

   ______ Yes ______ No Was it wet? ______ Was it dry? ______ Was it icy? ______

7. To your knowledge, do highway crews salt this bridge when there is a possibility of icing?

   ______ Yes ______ No

8. Do you have any reason to believe the bridge might be icy now?

   ______ Yes ______ No Why? ______ saw a sign (go to #10) ______ weather conditions

   ______ saw ice on pavement ______ other*

   *____

9. Did you see ice warning sign?

   ______ Yes ______ No (Stop verbal interview)

10. (Omit unless motorist saw sign) What did the sign say?

    ______________________ What did the sign look like?

    ______________________ Was the sign helpful? ______ Yes

    ______ No How? ______________________________

INTERVIEWER

Give motorists the fill-in portion and complete the following.

Vehicle ______ Color ______ Year ______

Estimate the Driver's Age ______ Sex ______

Weather ______ Time ______ Obvious Vehicle Defects ______

____

Rate vehicle appearance in terms of its being clean. Low ______ Intermediate ______ High ______

Stick Shift? No ______ Yes ______

Motorist's Fill-In Questions

"Please provide thoughtful consideration of these few questions. They are asked for research purposes only, and your answers will remain in strictest confidence."

1. What is your occupation?

____

PLEASE CIRCLE THE NUMBER WHICH BEST DESCRIBES YOUR FEELINGS.

2. How well do you like to drive an automobile at relatively high speeds on two-lane roads?

Unhappy	–3	–2	–1	0	+1	+2	+3	Happy

3. How well do you like to pass cars while driving at relatively high speeds on two-lane roads?

Unhappy	–3	–2	–1	0	+1	+2	+3	Happy

4. Everyone has experienced skidding on icy pavements. What would be your reaction in the event of such a sudden and unexpected skid?

Panic	–3	–2	–1	0	+1	+2	+3	Calm

5. How dangerous do you think this bridge you just drove over is under these weather conditions?

Dangerous	–3	–2	–1	0	+1	+2	+3	Safe

THANK YOU FOR YOUR TIME.

APPENDIX B

EXPRESSIVE DRIVING

By

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This appendix report will deal with the expressive aspects of the data collected for the curve study already described in the body of this report. In the main this discussion will be concerned with the variable of expressive self-testing, a variable which requires a word of explanation, but which need not be described at length here.

The concept of expressive self-testing is easily explained. If a student is given a vocabulary test, he is being tested. If he plays a word game, such as Scrabble, with another student, he is contesting. If he attempts to solve a cross-word puzzle, he is involved in self-testing. Drivers are tested when they apply for licenses and they contest when they race another. There are, however, no self-testing exercises for drivers which are generally recognized. All the same, drivers engage in self-testing when they pit their driving skills against the challenge of the road and its traffic in an expressive way. If they go faster than they need to; if they pass when it is unnecessary; if they drive longer than they have to or farther; or if they tail-gate, they are probably engaged in self-testing. The list, of course, of self-testing behaviors is almost endless.

In 1966 Roberts, Thompson, and Sutton-Smith published a paper, "Expressive Self-Testing in Driving," which showed that driving behaviors could be scaled in a self-testing scale and that positions on the scale were associated with a surprisingly large range of attitudes. A second paper, "Flying and Expressive Self-Testing" (Roberts and Wicke, 1971) showed that low self-testing Naval aviators showed more "judgmental accentuation" than did high self-testing aviators in that the low self-testers were more likely to respond strongly to symbols of threat. A third paper, "Expressive Constraints on Driver Re-Education" (Hutchinson and Roberts, 1972) used a different methodology, but it also showed that low self-testing Kentucky women were more likely to display judgmental accentuation than were high self-testing women. Finally, a small study, "Traffic Control Decisions and Self-Testing Values" (Roberts, Hutchinson, and Carlson, 1972), suggested that traffic engineers could be divided into high and low self-testers and their attitudes toward certain traffic control decisions were congruent with their placements on the self-testing scale. Additional studies are in preparation and it will not be long until there are further publications on this variable.

The comment should be made, however, that high and low self-testing behaviors and attitudes define action styles within a relatively closely defined situation. They are not personality variables in the conventional sense and there may be many causes behind them. They are simply estimations which hold within the context of driving.

The curve study described here is essentially a survey, and the self-testing information was obtained through a questionnaire. It has the advantage, though, of being able to supplement the questionnaire responses with accurately measured speeds through the curve (except where there is missing data). It is complicated by the fact that there were three sites, two weather conditions, and six sign conditions and that the number of respondents for any one of the thirty-six environmental conditions was small. Furthermore, the interviewing situation was one which favored a low self-testing bias for not many respondents will confess to a love for fast driving when they have just been stopped by a policeman.

Two questions in particular were used to measure self-testing attitudes. The first, "How well do you like to drive an automobile at relatively high speeds on two-lane roads?" emphasized fast driving and the second, "How well do you like to pass cars while driving at relatively high speed on two-lane roads?" pertained to fast driving combined with one form of highway interaction, i.e., passing. The questions called for responses on a seven point scale ranging from Unhappy −3 to Happy +3, but the distribution of responses was unusually low (probably because of the policeman). Nearly half of the respondents, for example, chose the lowest possible answer to the speed question. Under the circumstances, it is probably best to treat these scales as being ordinal and ultimately they may be divided into simple high and low.

The Goodman-Kruskal coefficient of ordinal association (G) for the speed scale and the passing scale is .605 (N = 338). The two scales are associated, but there are people who like to drive fast and who do not like to pass and vice versa. For the present it is best to consider the two measures separately.

A third question dealt with panic, "Everyone has experienced skidding on wet pavements. What would be your reaction in the event of a sudden and unexpected skid?" Panic −3 to Calm +3. There was a positive association between calmness and passing (G = .127) which is significant and there will probably be one between speeding and calmness when the scales are collapsed. In other words, high self-testers tend to be calm in skids and some low self-testers report panic.

There are positive associations between self-testing attitudes and speeds in the curves for specific sites and weather conditions, but it is difficult to aggregate the data. The speeds for the deepest parts of the three curves were grouped into deciles for each site and each weather condition (six conditions in all) and then respondents were grouped according to the deciles in which they fell. It is known, however, that the more conspicuous signs definitely reduced speeds so the full story will not be known until these constraints are taken into consideration. In any event the speeding seale and the passing seales were positively associated with the new deep curve speeding scale (G - .196 and G = .152). These are significant associations at the .01 level and they will be larger when the scales are collapsed. High self-testers drive faster and low self-testers drive slower.

Other work has shown that males and females are both high and low self-testers and that young and old can be both as well. In the case of the curve respondents, being male was positively associated with driving fast (G = .187), passing (G = .248), and self-reported calmness (G = .427). Youth was positively associated with fast driving (self-reported) (G = .317), passing (G = .207), and fast driving in the deep curve (G = .192). For these respondents, then, high self-testers tended to be male and young.

Other variables considered in the survey have expressive components. People who like to drive (other things being equal) will probably drive more miles per year than those who don't. The choice of car models aand the maintenance of cars is obviously relevant, but economie factors affect the situation. Many of the young, male self-testers, for example, can't afford to buy the vehicle of their choice. It is useful, however, to consider these variables for whatever they are worth.

One of the variables divided self-reported driving experience into three categories: less than 5,000 miles per year, 5,000-15,000 miles per year, and over 15,000 miles per year. This scale was positively associated with driving fast (G = .151), passing (G = .143), calmness (G = .225) and driving fast in the deep curve (G = .133). It was also associated with maleness (G = .793), low neatness of the car (G = –.122) and the presence of a stick shift (G = .322). High self-testers drive more.

Other work suggested that there is a preference among high self-testing drivers for stick shifts. This scale (presence or absence of a stick shift) was positively associated with the enjoyment of fast driving (G = .216) driving fast in the deep curve (G = .255), more miles per year (G = .322), good tires (G = .120), earlier year models rather than late model cars (G = .218), young ages on the part of the drivers (G = .429), cars which were not considered showy (G = .246) or neat (G = .303).

It has been thought that stick shifts give a feeling of greater control of a car and that this feeling would be more important to high self-testers. The present study confirms the association.

There was a strong positive association between the owners' estimates of the conditions of their tires and the judged condition of their tires. In other words, drivers knew the condition of their tires and, in a measure, driving with the poorer tires may have had an expressive component. Drivers with the better tires were more likely to have seen the test signs (G = .177); they were more likely to have made the appropriate response to the sign (G = .322); they were less likely to be driving a vehicle judged defective by the interviewer (G = .793); they were more likely to be driving a car considered showy by the interviewer (G = .296) or neat (G = .236); and, very importantly, they were more likely to be low self-testers on the passing variable (G = .127). Some high self-testers were using poorer tires.

The functions of driver display (i.e., ornate vehicles) in highway interaction are still not understood, but some unpublished studies suggest that such factors should be considered. Drivers of cars which were high on the "showy" scale were less likely to give a proper response in terms of recognition of the sign's message (G = –.220), less likely to give proper responses to the recognition of sign's appearance (G = –.127), more likely to drive late models (G = .285), less likely to be judged defective (G = .724), more likely to have good tires (G = .296), more likely to be neat inside (G = .344), more likely to have conventional shifts (G = .246) and marginally they were less likely to enjoy driving fast (G = .119). Cars with neat interiors were less likely to be driven by drivers with the most driving experience, (G = .122), more likely to be driven by motorists who thought that they had poor tires (G = .121), less likely to see the sign (G = .162), more likely to be late models (G = .376), more likely to be driven by females (G = .387), less likely to be judged defective (G = .811), more likely to be judged to have good tires (G = .236), and more likely to have conventional shifts (G = .303). Clearly there seems to be a "new car" variable, but the relationship between this variable and self-testing remains obscure. Further work will have to be done in this area.

Some miscellaneous associations are worthy of notice. Women reported less driving experience (G = .793). They were more responsive to the signs than the males. Older respondents were also more responsive to the signs. Other associations could be cited, but they would add little to the preliminary picture given here.

The remainder of this discussion will only deal with the driving behaviors observed on the curve described as Site 1 in the report. It will be recalled that the speeds of drivers on this curve were recorded in miles per hour at four loactions: (1) 200 feet in advance of the curve (switch pair 1), (2) entering the curve (switch pair 2), (3) in the tight curvature (swith pair 3), and (4) leaving the curve (switch pair 4). In addition, lane placement was recorded at the tight curvature location by measuring in feet the distances of the right wheels from the right edge of the pavement. In the discussion which follows, the speeds at the four switch pair locations and the differences in lane placements at the deep curvature location will be viewed as dependent variables.

It is plain that differing environmental conditions affected speeds and lane placements. Observations were made under a total of twelve different environmental situations. The curve itself, of course, did not change, but a complete set of observations was made when the pavement was wet and another set was made when the pavement was dry. Furthermore, each set included observations made under six different sign conditions.

Dealing with twelve environmental states is difficult enough to warrant dispensing with other variables. It must be recognized, however, that other environmental conditions such as the number and location of passengers in the car, the characteristics of the traffic flow at particular times, the time of day, etc. had their effects. For the present, though, these additional variables will be ignored.

The responses to the driving and passing questions were averaged and those respondents who had average scores of −1, −2, and −3 were placed in a low self-testing group while those with scores ranging from −.5 to +3 were placed in a high self-testing group. This division also placed the respondents into two groups of approximately equal size although missing data caused numbers to vary at specific switch pair locations. There were not enough very high self-testers at this curve to justify using a third group although such a group would have had a great deal of interest. Basically, this study contrasts low self-testers with all others, a group which includes both medium and high self-testers.

The use, then, of the high and low self-testing classifications, the wet and dry pavement conditions, and the six sign conditions produced twenty-four sets of speed observations for each switch pair location and twenty-four sets of lane placement observations for the deep curvature location. The means for each subgroup are presented in Tables B-2, B-5, B-8, B-11, and B-14. The three-way analysis of variance for the speeds at each of the four switch pair locations and for the lane placements at the deep curvature location are given in Tables B-1, B-2, B-3, B-4 and B-5. These analyses of variance were computed on an Olivetti programmable calculator using the prepared program described as a "Three-Way Analysis of Variance, Unbalanced or Balanced Layout, Weighted Squares of Means Method" in all instances, but when the interaction effects were found for the lane placement analysis of variance, a second program described as a "Three-Way ANOVA, Unbalanced Layout, Method of Unweighted Means" was used because of the limitations of the first program.

The speed observations made at the four switch pair locations can also be considered. Table B-1 shows that there are two main effects at the first location which was 200 feet in advance of the curve. Weather was not significant, but the sign conditions and the self-testing attitudes were. Table B-2 shows that there was a reduction of speed with the higher level signs and Table B-3 shows that sign condition 1 (no sign) differed significantly from the others and that sign condition 2 (low specificity and low conspicuity) differed from the others as well. Examination of the mean scores in Table B-2 shows that high self-testers drove faster than low self-testers.

The next set of tables for switch pair location 2 shows essentially the same picture, but self-testing on the one hand and sign conditions on the other account for more of the variance at higher levels of significance (see Table B-4). Table B-5 shows that the high self-testers drove faster than the low self-testers and that the more salient signs were associated with a reduction in speed. Table B-6 shows that sign conditions 1 and 2 continue to differ from the others and that the significance levels have improved. Furthermore, sign 3 differs from sign 6. Once again, there are only two main effects and no interactional effects.

In the tight curvature location (switch pair 3), there are three main effects (see Table B-7). Weather is now important and self-testing and sign conditions continue to account for more of the variance and, again, the significance levels have improved. The high self-testers drive faster than the low self-testers here and the higher level signs are associated with a reduction in speed (see Table B-8). Table B-9 shows that sign conditions 1, 2, and 3 can be contrasted with sign conditions 4, 5, and 6.

At the last loeation (switch pair 4), there are only two main effects, for weather has lost significance (see Table B-10). The high self-testers drive faster than the low self-testers and the higher level signs are associated with a reduction in speed (Table B-11). Table B-12 shows that the first three sign conditions differ from the last three.

Since there were no interactional effects, these tables show that high self-testers drive faster than low self-testers throughout the curve and that the sign conditions have an effect throughout the curve. Weather is important in the deep curve and it is also associated with the percentage of increase from the speed at the deep curve to the speed at the last location.

In a sense, all of the above findings were to be expected. It was thought that judgmental accentuation on the part of the low self-testers would produce a differential response to the signs, but this hypothesis has not been confirmed by the analysis thus far. Lane placement, however, seems to be a different matter for while there was only one main effect of significance (see Table B-13) in that high self-testers on the average drove more to the inside (closer to the center line) than low self-testers, there was an extremely important interactional effect involving self-testing and the sign conditions. Table B-14 shows that when there is no sign present (sign condition 1), the high self-testers drive more to the outside and low self-testers drive more to the inside. Thereafter, the high self-testers drive more to the inside and the low self-testers more to the outside with the exception of sign condition 3 in dry weather when the high self-testers drive more to the inside than do the low self-testers. Sign condition six seems to bring everyone to the inside. Clearly, signs and self-testing attitudes make a difference in lane placement in a complex way.

It would appear that the differing speeds at the various locations are most affected by the differing signs. Self-testing attitudes, however, account for almost as much variation in some situations and they always account for some variation. Both the sign conditions and the self-testing attitudes are more important in accounting for the differences in speed than the weather.

The lane placement data suggest that high and low self-testers differ in more than speed of driving for they must have different styles. Generally speaking, signs appear to make the high self-tester swing to the inside while the low self-tester drives to the outside. When there are no signs, their positions are reversed. There is a need for further research in driving styles which might explain these findings, for differences in styles might have important consequences.

Table B-1

Analysis of Variance: Speed at Site 1 (Switch Pair 1)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Self-Testing (High vs Low) A	137.65	1	137.65	4.082	$< .05$
Weather (Wet vs Dry) B	45.96	1	45.96	1.363	N.S.
Sign Condition (1, 2, 3, 4, 5, 6) C	552.82	5	110.56	3.278	$< .025$
Interaction	400.37	16	25.02	0.742	N.S.
Within Cells	3,338.72	99	33.72		
Total	4,475.52	122			

Table B-2

Speed Site 1 (Switch Pair 1)

		Sign Conditions						
	Weather	1	2	3	4	5	6	
High Self-Testers	wet	38.977	45.01	40.700	36.906	37.186	38.665	39.754
		n=3	n=6	n=8	n=5	n=6	n=8	n=36
	dry	45.248	41.153	n=39.572	42.72	42.794	37.1550	41.406
		n=5	n=3	n=6	n=2	n=5	n=4	n=25
Low Self-Testers	wet	41.767	41.834	41.477	36.154	32.640	32.520	38.711
		n=7	n=8	n=3	n=7	n=3	n=3	n=31
	dry	42.625	40.114	38.695	34.725	38.548	36.978	39.413
		n=8	n=7	n=2	n=2	n=6	n=6	n=31
		42.458	42.041	38.214	37.01	38.313	37.094	
		n=23	n=24	n=19	n=16	n=20	n=21	n=123

Table B-3

Significant Differences in Sign Conditions for Site 1 (Switch Pair 1)

	2	3	4	5	6
1	n.s.	$p < .01$	$p < .10$	$p < .10$	$p < .001$
2		$p < .05$	$p < .05$	$p < .05$	$p < .01$
3			n.s.	n.s.	n.s.
4				$p < .10$	n.s.
5					n.s.

Table B-4

Analysis of Variance: Speed at Site 1 (Switch Pair 2)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Self-Testing (High vs Low) A	149.48	1	149.48	5.590	$< .02$
Weather (Wet vs Dry) B	20.33	1	20.33	0.760	N.S.
Sign Conditions (1, 2, 3, 4, 5, 6) C	760.60	5	152.12	5.689	$< .001$
Interaction	217.95	16	13.62	0.509	N.S.
Within Cells	2674.02	100	26.74		
Total	3,822.38	123			

Table B-5

Speed Site 1 (Switch Pair 2)

		Sign Conditions						
	Weather	1	2	3	4	5	6	
High Self-Testing	Wet	36.838	39.535	36.869	33.308	33.825	32.1063	35.293
		n = 4	n = 6	n = 8	n = 5	n = 6	n = 8	n = 37
	Dry	41.582	36.587	34.923	35.135	36.265	33.685	36.553
		n = 5	n = 3	n = 6	n = 2	n = 4	n = 4	n = 24
Low Self-Testing	Wet	37.976	36.911	34.387	32.374	27.810	28.805	34.048
		n = 7	n = 8	n = 3	n = 7	n = 3	n = 4	n = 32
	Dry	38.221	35.644	34.555	29.220	33.257	32.527	34.759
		n = 8	n = 7	n = 2	n = 2	n = 6	n = 6	n = 31
		38.619	37.157	35.619	32.617	33.210	31.908	
		n = 24	n = 24	n = 19	n = 16	n = 19	n = 22	n = 124

Table B-6

Significant Differences in Sign Conditions for Site 1 (Switch Pair 2)

	2	3	4	5	6
1	n.s.	n.s.	$p < .001$	$p < .01$	$p < .001$
2		n.s.	$p < .01$	$p < .05$	$p < .01$
3			$p < .10$	n.s.	$p < .05$
4				n.s.	n.s.
5					n.s.

Table B-7

Analysis of Variance: Speed at Site 1 (Switch Pair 3)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Self-Testing (High vs Low) A	176.35	1	176.35	9.667	$< .005$
Weather (Wet vs Dry) B	75.97	1	75.97	4.165	$< .05$
Sign Conditions (1, 2, 3, 4, 5, 6) C	560.01	5	112.00	6.140	$< .001$
Interaction	170.55	16	10.66	0.584	N. S.
Within Cells	1,824.25	100	18.24		
Total	2,807.13	123			

Table B-8

Speed Site 1 (Switch Pair 3)

	Weather	Sign Conditions: No sign	2	3	4	5	6	
High Self-Testers Average of 3.5 or more	wet	35.518 n=4	37.795 n=6	36.100 n=8	33.146 n=5	34.202 n=6	32.664 n=8	34.619 n=37
	dry	37.160 n=3	40.998 n=5	36.325 n=6	36.445 n=2	36.310 n=5	33.293 n=4	36.881 n=25
Low Self-Testers Average of 3 or less	wet	36.403 n=7	35.658 n=8	32.067 n=3	32.511 n=7	28.373 n=3	29.465 n=4	33.339 n=32
	dry	37.93 n=8	36.089 n=7	35.660 n=2	28.715 n=2	34.025 n=6	31.610 n=6	34.794 n=31
		36.901 n=22	37.294 n=26	35.488 n=19	32.727 n=16	33.802 n=20	31.909 n=22	n=125

Table B-9

Significant Differences in Sign Conditions for Site 1 (Switch Pair 3)

	2	3	4	5	6
1	n.s.	n.s.	n.s.	$p < .05$	$p < .001$
2		n.s.	$p < .01$	$p < .01$	$p < .001$
3			$p < .10$	n.s.	$p < .05$
4				n.s.	n.s.
5					n.s.

Table B-10

Analysis of Variance: Speed at Site 1 (Switch Pair 4)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Self-Testing (High vs Low) A	102.82	1	102.82	5.433	$< .025$
Weather (Wet vs Dry) B	0.20	1	0.20	0.011	N.S.
Sign Conditions (1, 2, 3, 4, 5, 6) C	502.28	5	100.46	5.308	$< .001$
Interaction	268.65	16	16.79	0.887	N.S.
Within Cells	1,892.42	100	18.924		
Total	2,766.37	123			

Table B-11

Speed Site 1 (Switch Pair 4)

		Sign Conditions						
	Weather	1	2	3	4	5	6	
High Self-Testing	wet	35.798	39.260	37.981	34.886	35.118	35.578	36.500
		n=4	n=6	n=8	n=5	n=6	n=8	n=37
	dry	41.962	36.823	36.677	34.630	36.106	32.793	36.852
		n=5	n=3	n=6	n=2	n=5	n=4	n=25
Low Self-Testing	wet	37.65	37.498	33.720	34.458	31.927	31.165	35.222
		n=7	n=8	n=3	n=6	n=3	n=4	n=31
	dry	39.348	36.264	34.230	28.43	36.375	32.475	35.711
		n=8	n=7	n=2	n=2	n=6	n=6	n=31
Total		38.806	37.494	36.502	33.820	35.263	33.423	
		n=24	n=24	n=19	n=15	n=20	n-22	n=124

Table B-12

Significant Differences in Sign Conditions for Site 1 (Switch Pair 4)

	2	3	4	5	6
1	n.s.	n.s.	$p \leq .01$	$p \leq .05$	$p \leq .001$
2		n.s.	$p \leq .05$	$p \leq .10$	$p \leq .01$
3			$p \leq .10$	n.s.	$p \leq .05$
4				n.s.	n.s.
5					n.s.

Table B-13

Analysis of Variance: Lane Placement (Switch Pair 3)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	P
Self-Testing (High vs. Low) A	0.810	1	0.810	6.542	$<.025$
Weather (Wet vs. Dry) B	0.117	1	0.117	0.336	n.s.
Sign Conditions (1, 2, 3, 4, 5, 6) C	0.970	5	0.194	1.567	n.s.
A B	0.051	1	.051	0.409	n.s.
A C	3.648	5	0.730	5.892	$<.0005$
B C	0.551	5	0.110	0.890	n.s.
A B C	1.234	5	0.247	1.992	$<.10$
Within Cells	11.392	92	0.124		
Total	18.773	115			

Table B-14

Lane Placement Site 1 (Switch Pair 3)

		Sign Conditions						
	Weather	1	2	3	4	5	6	
High Self-Testers	Wet	1.990 N=4	2.927 n=6	3.138 n=8	2.730 n=5	3.580 n=6	3.200 n=6	2.999 n=35
	Dry	2.500 n=5	3.28 n=3	2.225 n=6	3.900 n=2	2.825 n=4	3.120 n=4	2.803 n=24
Low Self-Testers	Wet	3.360 n=6	2.389 n=7	1.960 n=3	1.828 n=6	2.217 n=3	3.055 n=4	2.504 n=29
	Dry	3.271 n=8	2.020 n=6	2.740 n=2	1.900 n=2	2.350 n=4	3.262 n=6	2.740 n=28
		2.904 n=23	2.557 n=22	2.622 n=19	2.427 n=15	2.872 n=17	3.174 n=20	n=116

APPENDIX B
REFERENCES

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