Evaluation of Signing to Warn of Wet Weather Skidding Hazard

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This field study examined driver responses to the potential skidding hazard of wet pavements subjected to high frictional driving demands. Study objectives were to examine motorists' general awareness of the hazard and to assess the relative effectiveness of various signing treatments that warn of the hazard. Measures of signing effectiveness were motorists' speeds at critical curve 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 to 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. Signing without flashing lights was not shown to be effective. Those questioned 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 accident history of site, and presence of the warning sign. About 1 percent of the interviewed motorists cited the warning sign as their cue of potential skidding hazard.

The development of human factors techniques aimed at the reduction of skidding accidents is long overdue. For more than 2 decades, highway researchers have directed their efforts almost exclusively to studying tire-pavement interactive phenomena. Concurrently, developments of the automotive industry have been primarily limited to radial tires and antiskid braking devices. No systematic 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.

Investigation of driver reaction to environmental elements that affect the operation of the vehicle is a necessary approach toward the prevention of skidding accidents. This follows from the fact that skidding accidents generally occur because the motorist is unaware of an existing threat. Therefore, this research was undertaken to seek an effective means of warning drivers of the potential hazard.

Publication of this paper sponsored by Committee on Motorist Information Systems.

The objective of this study was to assess the effectiveness of signing to warn of the wet pavement skidding hazard. Various levels of signing were achieved through the use of flashing lights and messages of varying specificity. Measures of signing effectiveness were vehicle speeds at critical curve locations and driver questionnaire responses. In addition, driver cues of the hazard were determined from the questionnaire.

BACKGROUND

Driver awareness of skidding accident potential remains virtually undocumented. However, one study undertaken in the Netherlands did examine steering and driver detection of skidding (1). A systems approach to identify factors affecting the skidding accident noted that the role of drivers is difficult to determine because of inherent differences in psychological and physiological conditions (2). Yet these conditions do affect accident occurrence (3), and their effects are transitory (4).

Hankins and others identified components of the driver's communication system relevant to skidding accidents (2). In addition to traffic signs, signals, and markings, certain geometric features (curvature, guardrails, and delineation devices) were noted to have the potential of communicating a skid hazard, yet the relative effect on the motorist of these communicative devices is unknown. Sparse documentation exists regarding the effects of curvature; conflicting safety implications result from signing studies; and no prior documentation exists regarding driver reliance on any of the devices as a hazard cue. There is evidence that drivers rely on their perception of curve geometry to select curve entry speeds regardless of advisory speed signing (5). Furthermore, speed studies of advisory speed signs have shown them to be ineffective (6). This finding seems to confirm other field studies that indicate that motorists ignore general speed limit signing (7, 8). However, there is strong conflicting evidence that signing that is sensitive to specific conditions can provide an effective remedy. A before-and-after study of advisory speed limit signing in combination with standard curve warning signs demonstrated a significant reduction in single vehicle

accidents (9). A variety of curve warning signs were studied in Finland by using speed data in combination with 2768 driver surveys (10). Results showed that driver recognition and deceleration in response to specific speed limit signing were better than the response to more general warning signs.

It is well known that, for signing to be effective as a hazard cue, it must be credible to the driver (11, 12, 13). Activated warning signs have been shown to be effective in the presence of a hazard that is perceivable to the driver (7, 14, 15).

PROCEDURE

Study Design

The structure of this field study is a two-dimensional examination of signing treatment effects across roadway surface conditions. Data were derived from a population of motorists negotiating curved sections of roadway. Independent variables and their parameters are signing (varying levels of conspicuity and specificity) and pavement condition (varying levels of slipperiness due to wetness). Dependent variables to describe signing effects were vehicle performance measures (speed, intervehicle gap, position on roadway, mean acceleration and deceleration) and 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) and their observations relating to hazard (assessment of safe wet pavement speed, cue of potential skid hazard).

Parameters of roadway wetness were dry condition and wet condition. The dry condition was defined as a pavement that was dry in appearance when no rainfall had been evident for a considerable period. The wet condition was in effect when there was measurable rainfall or water film depth on the pavement. An attempt to quantify pavement skid resistance by using a decelerometer was not successful because obtained readings were not sensitive to rainfall onset and termination. Variables to describe signing condition were specificity (the extent to which specific instructions advising of hazard-responsive action were provided to the driver) and conspicuity (the use of flashing hazard beacons). Low specificity signing consisted of the symbolic SLIPPERY WHEN WET panel with no supplementary wording. Moderate specificity signing that required some assessment on the part of the motorist was 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 provided explicit instructions through the provision of an advisory speed limit. Two levels of conspicuity were high and low; the high level was achieved by the addition of two standard yellow flashing beacons to the standard or low level sign. Figure 1 shows sign conditions that were tested. Six signing conditions ranged from condition 1, the no-sign condition, to condition 6, which was made up of high levels of both conspicuity and specificity.

Field Sites

To permit the evaluation of signing treatments under diverse, potentially skid-hazardous driving conditions, three field study sites were selected on the basis of differing cornering characteristics. Each site represented a potential skidding hazard as determined by accident history and site geometry. All sites permitted examination of driver acceleration and deceleration behavior. Site 1 was the target of primary interest because its curvature of 20 deg was characterized by high driver cornering forces (16). In addition, the availability of pavement skid resistance data at site 1 permitted computation of the critical wet weather speed. Sites 2 and 3 were used to confirm or refute site 1 observations.

Data Collection Methodologies

Two primary data collection techniques were employed. Vehicle performance data were gathered by using the traffic evaluator system (TES), and driver characteristic data were obtained by questionnaire.

Traffic Evaluator System

TES consists of unobtrusive pavement sensors, a recorder and electronics unit, power supplies, manual code boxes, associated cabling, and a set of computer programs for reconstruction of the original vehicle characteristics. Pavement sensors convey vehicle presence data to the recorder where they are stored in digital format for computer processing. Computer programs are used to prepare data obtained in the field with TES. These programs translate time and switch codes into vehicle and traffic flow histories, reproducing the conditions actually experienced on the roadway. A complete description of the TES is available elsewhere (19, Part 2, Appendixes A and B).

Driver Questionnaire

Interviewing of motorists was conducted during the testing of all experimental signing conditions and under all ambient conditions studied. Drivers' questionnaire responses were matched with their vehicle speed data. Interview sites were located beyond driver sight distances from the curve to permit the acquisition of unbiased speed data. Vehicles selected for driver interviewing were those exhibiting such sufficient headways that their speeds were not influenced by others in the traffic stream.

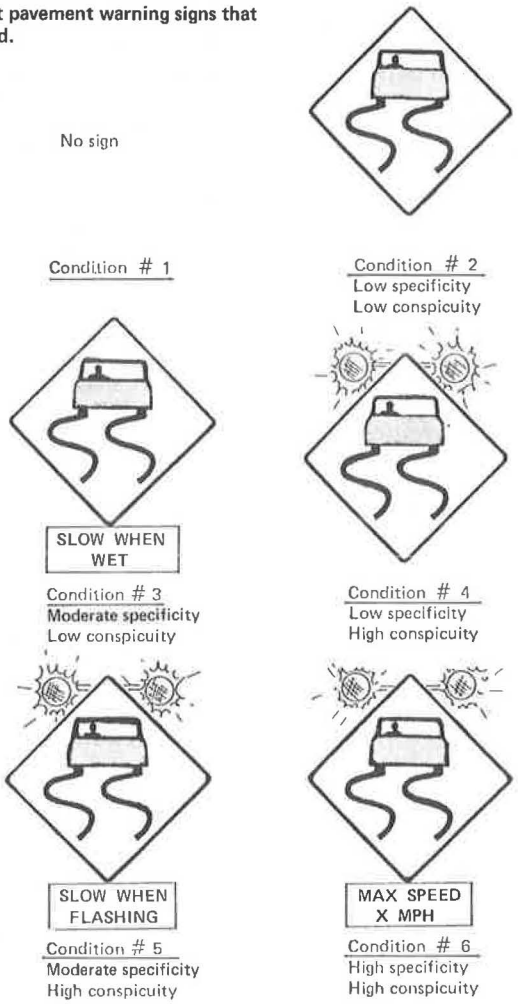
An interviewing strategy was adopted to permit certain driver characteristic data to be obtained before the driver knew that the study related to potential skid hazard. After a brief introduction that advised the motorist that a safety study was being conducted, the driver was asked about his or her skidding experience both at the site and within overall driving experience. Drivers were asked for an assessment of the potential skidding hazard and what their cues of the hazard were. In cases where the experimental sign was not cited as the cue, drivers were asked if they had seen the sign.

ANALYSIS AND RESULTS

Vehicle Performance Data

Specific measures derived from the TES were vehicle speeds, accelerations, lateral placements, and intervehicle gaps. Data collection points on each roadway curve consisted of an advance location [60 m (200 ft) in advance of the curve], the curve entry point, the point of sharpest curvature, and the curve exit point. The literature has overwhelmingly demonstrated the importance of speed as an indicator of skidding hazard. Therefore, speeds of individual vehicles became the primary TES measure of effectiveness used to examine

Figure 1. Wet pavement warning signs that were evaluated.



motorists' responses to varying hazard situations and experimental warning sign conditions. Intervehicle gaps were used for selecting free-flowing vehicles for speed analyses.

As noted earlier, 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:

1. Normative (unobtrusive or no signing and dry pavement throughout all times of day to determine normal driving patterns);
2. Dry pavement both with and without signing to determine dry pavement effect; and
3. Wet pavement both with and without signing to determine wet pavement effect.

Site 1

Wet pavement data were collected in two attempts for all experimental signing conditions. In each case, light rainfall began before the data collection period and ended during the procedure. Pavement slipperiness was monitored by using the decelerometer technique to monitor the effects of rain stoppage. Data collection was terminated before any detectable effect of rain stoppage.

The critical wet weather driving speed, based on site roadway geometry and pavement skid resistance qualities, was calculated by using a method reported by Weaver, Hankins, and Ivey (17). The calculated speed of 61.1 km/h (38 mph) was exceeded by the highest quartile speed driver group at the tight curvature, which showed that this driver group is the appropriate target sample to be studied.

Using this sample, Figure 2 shows mean speed effects of sign conditions tested on 1 data collection day.

Figure 2. Mean speeds of highest quartile motorists depicting experimental signing effects during wet pavement conditions at site 1 on day 1.

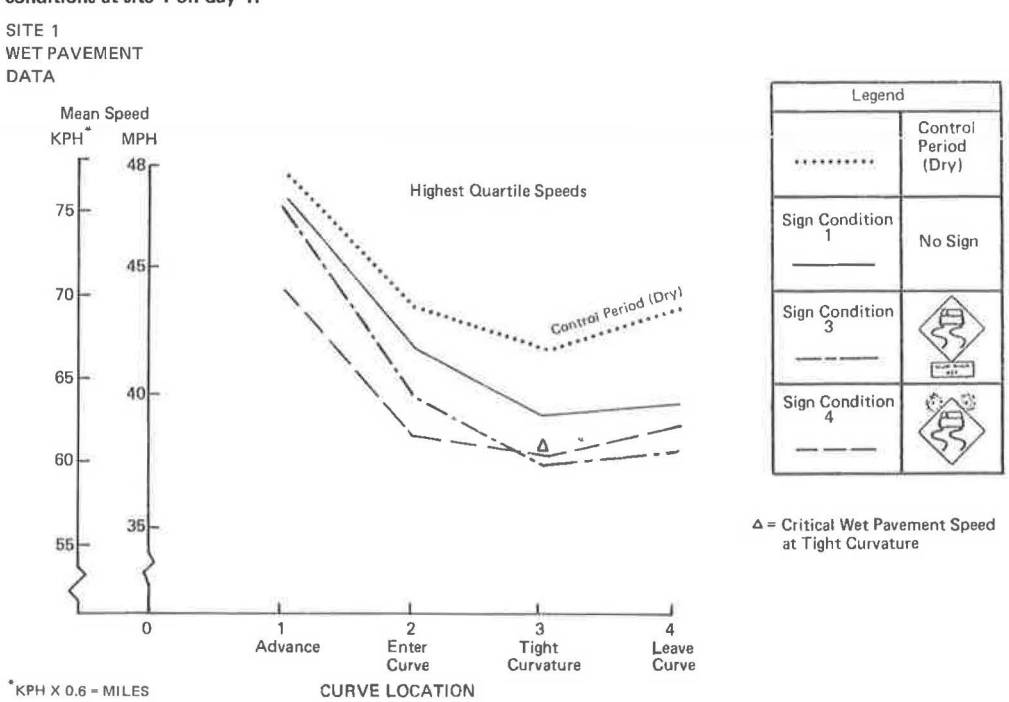
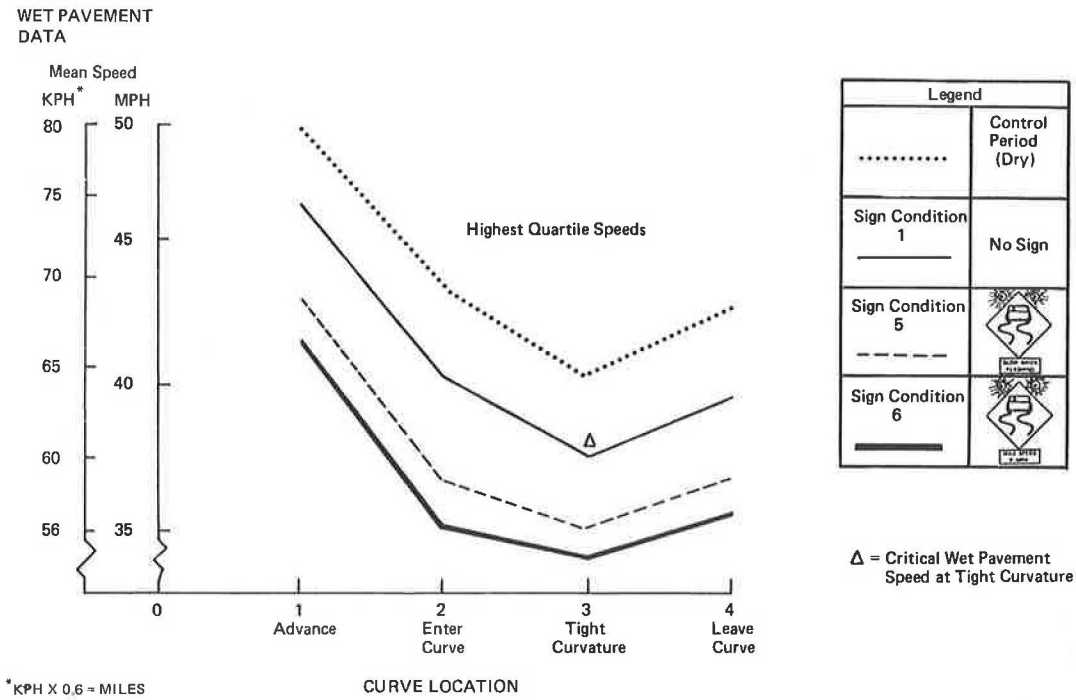


Figure 3. Mean speeds of highest quartile motorists depicting experimental signing effects during wet pavement conditions at site 1 on day 2.



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, SLIPPERY WHEN WET used by itself, were virtually identical to those observed during the no-sign condition; therefore, 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 shows data collected on another data collection day (Figure 3). 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 previously done. Some benefit appears to be derived from high specificity wording (MAX SPEED—35 MPH) over moderate specificity wording (SLOW WHEN FLASHING). Speeds observed for the no-sign condition were below the critical wet pavement speed. This difference from the data of the previous day was due to a higher proportion of familiar motorists in the traffic stream because data were collected in the late afternoon as commuters were returning home from work.

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. Comparisons were made of mean highest quartile speeds obtained under normal driving and experimental signing conditions. 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. These data were seen to bear out the evidence that familiar motorists on the second day were more sensitive to the wet pavement condition without signing than they were on the first day.

A number of observations can be made 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 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 that 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 (6). No significant effect on deceleration was observed as a function of the signing because 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.

Sites 2 and 3

In an attempt to determine the generalizability of driver responses, similar data were gathered at sites 2 and 3. Analyses identical to that described for site 1 were applied to the data. However, in the interest of brevity, only the results of these analyses are presented.

Site 2 wet pavement data generally confirmed site 1 observations in that the use of signs with flashing beacons resulted in significant decreases of both the total sample and highest quartile mean speeds both in advance of the curve and in the tight curvature. Dry pavement data results were the same as those for site 1 in that significant speed reductions were generally realized with activated signs.

At site 3, a lower speed site, all higher level signing produced significant speed reductions in advance of the curve. Fewer significant speed reductions were observed in the tight curvature because of low normal operating speeds [about 32 km/h (20 mph) average]. Dry pavement results were similar.

Overview of Sign Effects

Generally consistent effects of experimental signing to warn of potential skidding hazards were observed at all three sites. With one exception, no evidence supported the use of low conspicuity signing. At site 1, the use of low conspicuity, moderate specificity signing (SLOW WHEN WET) elicited significantly reduced motorist speeds at the curve entry point and in the tight curvature during wet pavement conditions. However, this observation was not replicated at either site 2 or site 3.

Sufficient site characterization data at site 1 permitted a comparison of observed motorists' speeds; the critical wet pavement speed was based on the site geometry and pavement characteristics. All high conspicuity experimental signing caused almost all motorists to drive below that speed during wet pavement conditions. Substantial speed reductions obtained at the remaining sites with high conspicuity signing displayed during wet pavement conditions corroborated that the flashing beacons were more 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 because speed reductions due to flashing signs were initiated sufficiently in advance of the test curves.

Driver Survey Data

This analysis is based on 305 driver interviews gathered during wet and dry pavement conditions with and without the presence of experimental signing. Vehicle speeds for each interviewed motorist were matched to his or her questionnaire responses. Questionnaire responses were categorized into 26 variables, and variable-paired comparisons were obtained through regression analysis. Variables were assigned to the following categories: signing, pavement condition, driver responses to signing, general driver characteristics, vehicle characteristics, and observed vehicle speeds.

Sign Condition

Drivers at all sites were more prone to observe and properly identify the appearance of the higher level signing. However, the proper identification of sign wording did not increase with higher level signing. The more conspicuous signing called attention to itself but did not arouse motorists' attention to the point of increased retention of sign wording. However, drivers were more likely to identify the higher specificity wording. 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 (10). To be credited with 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 suffice as a correct response if the displayed sign was SLOW WHEN WET. At one site, more specific signing was viewed by motorists as being more helpful.

When highly conspicuous signing conditions were used, significantly more motorists saw and correctly identified the sign. Motorists gave lower estimates of safe wet speeds when highly conspicuous signs were displayed.

The relative effects of sign specificity and conspicuity were reflected by their respective correlations with speeds of interviewed motorists. The 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 motorist recognition of sign wording implies a reduction of speed due merely to the presence of the flashing beacons.

Pavement Condition

The effect of wet pavement was seen at one site in a motorist scalar rating of skidding danger associated with prevailing conditions. Motorists rated the site as more hazardous during conditions of wet pavement.

Driver Responses to Signing

Motorists' responses to signing consisted of (a) observation of skid hazard warning sign, (b) identification of appearance and message of sign, and (c) assessment of helpfulness of sign. Expansion and clarification were obtained on point c by asking how the sign was helpful.

Observation

The use of higher level and high conspicuity signing conditions resulted in more motorists observing the signing at all sites. No significant differences were noted in motorists' observation rates between the highly conspicuous signing conditions. The signs were more often seen by familiar motorists at one site. Forty-four percent of first-time motorists saw the signs. Motorists at one site who saw the sign gave a lower estimate of safe wet weather driving speed. Sign observation also affected motorists' speeds. Those drivers who saw the experimental signs negotiated the entire curve at lower average speeds at one site and slowed for the tight curvature at another site.

Recognition of 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 sign appearance. This finding is consistent with that for the familiar motorists who were more likely to observe the signing.

Recognition of Wording

The use of higher specificity signing resulted in more motorists properly recalling sign wording at all sites.

Motorists who reported prior skidding experience were less likely to recognize wording on the test signs. Drivers at one site who drove fewer kilometers per year were more likely to recognize sign wording. There were no correlations between motorists' speeds and their having properly read the test signing.

Assessment as Helpful

Higher level signs and more specific sign wording were rated as being more helpful by motorists at one site. Those drivers who thought the posted speed limit should be higher were less prone to regard the test sign as helpful. It is noteworthy that motorists who designated the signing as being helpful did not drive through the 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 with 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.

Familiarity With Site

Familiar motorists were more likely to see test signing at one site. Those familiar drivers who saw the signing exhibited a greater tendency than unfamiliar drivers to properly recall sign appearance. At another site, the more familiar motorists rated the sign as being helpful.

The drivers' reactions to potential skid hazard, taken on the basis of their familiarity with the site, were mixed. A trend was evident in that the more familiar d drivers at one site were less likely to assess the site as a hazard, and the more familiar drivers elsewhere thought that posted speed limits were too low. However, that the more familiar motorists consistently exhibited lower speeds indicated 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 one site, those motorists who said that the posted speed limit should be higher exhibited higher speeds as they drove through the site. Motorists interviewed while the pavement was wet were more likely to say the posted limit was too low because it pertained to the dry pavement condition. At another site, drivers who asserted that the speed limit should be higher were the ones with the most skidding experience at the site.

At both sites, motorists who wanted the higher speed limits were the more familiar ones and the ones less likely to perceive the site as a skid hazard. 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 gave lower estimates of safe wet weather driving speeds. This effect of experimental signing is compatible with the fact that motorists at one site who did not see the signing gave higher estimates.

Positive correlations between motorists' driving speeds and estimated safe wet speeds were observed. Those drivers who gave higher wet pavement speed estimates also thought the posted speed limit was too low. Higher estimates were given by male drivers and by those motorists who currently drive the most kilometers per year.

Driving Practice

Annual kilometers per year driven was taken to be an indicator of the level of current driving practice. Drivers with more practice gave higher estimates of safe wet driving speed, indicated that they would react more calmly in the event of an unexpected skid, and drove through the curve faster than those with less practice. Male drivers indicated more practice than female drivers at both sites.

Driver Age

Of those motorists who saw the experimental signing, the older ones were more likely to describe the sign as being helpful. Older drivers were less 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 before and beyond the curves. Mean driver age in the sample was 39 years.

Sex of Driver

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; females reported 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.

Assessment of Skid Hazard

Interviewed motorists were asked whether they believed that the curve that they had just driven through might be a skid hazard. Those who answered yes were queried on the hazard cue. 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. Younger drivers were also more likely to assess the site as potentially hazardous. At one site, fewer motorists assessed the site as a potential skid hazard 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 this sample who had skidded elsewhere on highway sections other than at curves were more likely to rate the site as a hazard.

Seventy percent of the 305 interviewed motorists 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, and

8. Other reasons.

Responses were categorized by numbers and percentages of motorists who cited each cue according to site, pavement condition, and presence of a skid warning sign. The proportion of drivers who cited each cue remained fairly constant over all conditions. About one-third cited sharp curvature; about one-sixth cited driving behavior of other motorists; and almost one-third said 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 response comparisons, the primary hazard cue was sharp roadway curvature. During wet pavement periods, some motorists' attention was diverted to pavement that 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 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.

Contrasting cue responses between conditions with and without warning signs reveals minor differences. Significantly fewer motorists assessed one site (site 1) as a potential skid hazard while test signs were displayed. The data indicate 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. The emergence of more diverse cues during the presence of signing might indicate that motorists were 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; therefore, no conclusive evidence was found to indicate that the signing had any impact on motorists' perception of skid hazard.

CONCLUSIONS

Summary and Findings

This field study investigated the driver's general awareness and his or her response to warning signs for the hazard of wet pavements subjected to high driver frictional demands. Three curved highway sections were treated by 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 made up of variations of the SLIPPERY WHEN WET symbolic sign, ranging from its use by itself to increasing levels of specificity and conspicuity to its use with flashing beacons and an advisory speed limit.

The primary measure of signing effectiveness was mean speed at critical curve locations. The highest quartile speed group (fastest 25 percent) of vehicles arriving in advance of the curve was selected as the target sample. Significant speed reductions at critical curve locations were observed to result from signing that employed flashing hazard beacons. Higher speed reductions generally resulted from the supplementary use of advisory speed limits. These observations took into account normal hour-to-hour speed variation. Three study sites were used to establish generalizability of results.

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; sign conspicuity had a greater impact than specificity. The more familiar motorists were more likely to see the signs, and those with greater driving practice were more likely to read them. However, the experimental skid hazard warning signs were shown to have a marginal effect on motorists' verbal assessment of the site as 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 kilometers 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 because 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.

Recommendation

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 before rainfall rather than from permanent installations to which motorists had become accustomed. In addition, the experimental design incorporated in this study did not provide for a specific examination of novelty effect. Furthermore, the literature has shown poor driver responses to continuously displayed warning devices. Thus 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 from the field observations of this study only. 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 that use of the advisory speed limit sign is considered prudent on the part of highway agencies (18), and favorable accident rate effects have been shown to result from the use of advisory speed limits on curve warning signs (9). A documented technique to determine applicable wet weather speed limits is available (17).

The recommendation follows that activated warning signing be used as a skidding accident reducing countermeasure. Specifically recommended signing is that designated in the Manual on Uniform Traffic Control Devices (MUTCD) (20) 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 ensure that beacon flashing will terminate as the pavement becomes dry. Sign location with respect to the curve

should be in accordance with current practice.

ACKNOWLEDGMENT

The field study reported in this paper was sponsored by the Federal Highway Administration and conducted under contract DOT-FH-11-7972. The contract manager was Alfred G. Klipple to whom appreciation is expressed for permission to publish this study.

REFERENCES

1. G. I. Burgt and J. Hart. Steering/Skidding Correction. Vehicle Research Laboratory, Delft Technical Univ., Netherlands.
2. K. D. Hankins and others. Skidding Accident Systems Model. Texas Transportation Institute, Texas A&M Univ., College Station, Research Rept. 135-1, March 1971.
3. R. A. McFarland. Human Factors in Highway Safety: A Review and Evaluation. New England Journal of Medicine, No. 256, 1957, pp. 837-845.
4. M. L. Selzer and A. Vinokur. Life Events, Subjective Stress, and Traffic Accidents. American Journal of Psychiatry, Vol. 131, No. 8, 1974, pp. 903-906.
5. M. W. Ritchie. Choice of Speed in Driving Through Curves as a Function of Advisory Speed and Curve Signs. Human Factors, Vol. 14, No. 6, 1972.
6. G. J. Bezkorovainy. The Influence of Horizontal Curve Advisory Speed Limits on Spot-Speeds. Traffic Engineering, Sept. 1966, pp. 24-28.
7. H. R. Brackett. Experimental Evaluation of Signing for Hazardous Driving Conditions. Virginia Council of Highway Investigations and Research, Charlottesville, Progress Rept. 2, March 1965.
8. C. Wiley. Effect of Speed Limit Signs on Vehicular Speed. Department of Civil Engineering, Univ. of Illinois, Urbana, Sept. 1, 1969.
9. C. G. Hammer. Evaluation of Minor Improvements. California Division of Highways, Part 6, May 1968.
10. S. Hakkinen. Perception of Highway Traffic Signs. Central Organization for Traffic Safety in Finland, Helsinki, 1965.
11. A. Howard. Traffic Sign Recognition. Proc., Canadian Good Roads Association, Oct. 1964.
12. D. I. Williams and M. D. van der Nest. The Human Factor in Road Traffic Signs: The View of the Road User. Council for Scientific Industrial Research, Johannesburg, South Africa, Rept. CSIR PERS 113, May 1969.
13. W. T. Jackman. Driver Obedience to Stop and Slow Signs. HRB, Bulletin 161, 1957, pp. 9-17.
14. M. L. Reiss. School Trip Safety and Urban Play Areas. MAUDEP Bicycle/Pedestrian Planning and Design Conference, San Diego, Calif., Dec. 1974.
15. F. R. Hanscom. An Evaluation of Signing to Warn of Potentially Icy Bridges. TRB, Transportation Research Record 531, 1975, pp. 18-35.
16. A. Taragin. Driver Performance on Horizontal Curves. Proc., HRB, Vol. 33, 1954, pp. 446-466.
17. G. D. Weaver, K. D. Hankins, and D. L. Ivey. Factors Affecting Vehicle Skids: A Basis for Wet Weather Speed Zoning. Texas Transportation Institute, Texas A&M Univ., College Station, 1973.
18. D. C. Oliver. Build the Best, Safest Highways Possible to Avoid Legal Liability as a Government Traffic and Transportation Engineer. Traffic Engineering, Vol. 44, No. 7, 1974.
19. Diagrammatic Guide Signs for Use on Controlled Access Highways. In Traffic Engineering Evaluation of Diagrammatic Guide Signs, Federal Highway Administration, FHWA-RD-73-25, Vol. 3.
20. Manual on Uniform Traffic Control Devices. Federal Highway Administration, 1971.