AN EVALUATION OF SIGNING TO WARN OF POTENTIALLY ICY BRIDGES

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This field study examined driver responses to a potentially slippery bridge during periods of possible preferential icing. Study objectives were to examine motorists' general awareness of the hazard and to assess the relative effectiveness of various warning sign treatments. Measures of signing effectiveness were motorists' speeds at critical bridge approach locations and questionnaire responses regarding motorists' observations and interpretations of the signs. Two bridge approaches were signed with combinations of activated and nonactivated signs at the bridge and 1,000 ft (305 m) before the bridge during periods of possible preferential icing. Significant speed reductions on the bridge and at the bridge entry were elicited by activated signing. The most effective signs were (a) activated, before the bridge and (b) activated, at the bridge during hours of darkness. Activated signing used at the bridge was observed to have a greater impact than activated signing used before the bridge. Drivers were more responsive to the signs during hazardous periods. Bridge-approach roadway geometry was seen to affect motorists' observation of and response to the signing. Improved results were obtained on a short sight-distance approach where the bridge did not visually compete for driver attention.

•LOCALIZED bridge icing poses a severe threat to motorists' safety throughout much of the year in many regions. Traffic engineering problems associated with remedying this threat are compounded by many diverse issues: unreliability of ice detection devices, complexities of legal liability, and credibility of motorists' warning devices. The first of these issues is the subject of much past and current research; the second is the subject of many past and current tort liability suits; and the third represents a critical research need. The purpose of the work described in this paper is the development of effective signing to warn motorists of an icy bridge hazard. The subject experiment is a field evaluation of 8 signing schemes that were derived from a review of the literature, a survey of current operational practice, and a preference test.

PREFERENTIAL ICING HAZARD

Preferential icing of bridge decks, a well-known but elusive safety hazard, is the formation of ice on bridge decks when approach roadways may not be icy. Ice will form on any surface when the temperature of that surface is 32 F (0 C) or lower and moisture is applied. There are 2 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; the rate at which condensation occurs when the temperature is 32 F (0 C) or lower results in formation of frost on the surface (13). Icing of the surface is caused by precipitation when the surface temperature is 32 F (0 C) or lower. Preferential icing of bridge decks occurs when bridge surface temperature is at or below freezing and the approach

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roadway is warmer (because of the earth's heat). The most conducive environmental conditions are moderate daytime temperatures, high relative humidity, and subfreezing night temperatures.

Research has been undertaken to correlate the variables of weather, geographic location, and bridge-deck thermal properties, which lead to preferential icing (2). A study of ice and snow detection and warning system feasibility provides much detail on the physical and meteorological aspects of the problem, highway department maintenance and warning policies, and legal aspects (8).

PRIOR STUDIES

Considerable detailed literature describes ice-detection and warning systems that generally include a warning sign as 1 component of the system (1, 2, 3, 4, 5, 7, 8, 10, 12, 14). However, relatively little effort has been devoted to evaluating motorists' responses to the sign (1, 6, 8, 14). Ice-detector and sign use remains undocumented in a number of states, and research is in progress in others.

A summary of documented ice warning sign evaluations is shown in Figure 1. A Colorado study (1) examined the operation of 2 ice warning systems, but it did not study motorists' responses to the signs. However, a noteworthy observation in the report was that static signing "inconsistent with prevailing conditions" generally was disregarded by motorists. This observation is compatible with one made in the California study that asserted that static ice or frost warning signs are ineffective because they are continuously visible to the motorist (14). These 2 observations, though subjective, substantiate the well-documented fact that motorists are more likely to respond to a warning sign in the presence of a perceived hazard (9, 11, 15). The California study also 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. The authors

Figure 1. 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.

Note: 1 mile = 1.6 km.

stated that the results were 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 static WATCH FOR ICE ON BRIDGE signing was conducted in Ohio (5). Before-and-after accident reduction rates were analyzed for 24 site pairs, each of which comprised a test and control bridge location. Signing was placed at test sites during winter months for 3 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 (5). Significant reductions were noted for wet and dry as well as icy conditions. The signing used was identical to the WATCH FOR ICE ON BRIDGE used in this study and similarly was located before bridge locations.

A field evaluation of motorists' responses to an ICY BRIDGE AHEAD sign was conducted as part of the Glauz et al. study (8). The fixed message sign, an advisory speed limit panel, and an amber flashing light were mounted on a rotating frame so that they could be displayed to motorists when conditions warranted. Data collected during the experiment included: (a) vehicular speeds, (b) traffic volume by lane, (c) lane change frequency, (d) brake-light occurrences, and (e) motorist interviews. The principal measure, speed reductions between the bridge approach and the upstream location, showed a statistically significant increase during 3 of 4 periods when the sign was displayed. Average speed reductions of 7 mph (11.3 km/h) were attributed to the signing; larger reductions occurred during periods of localized icing. The data showed no significant effect of the sign on lane change distribution at the bridge, although there was a suggestion that the sign caused some weaving from the right lane to the center of 3 lanes. The data also suggested that during the 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, when ice or packed snow was on the approach, the warning sign appeared to increase the amount of braking on the bridge approach. The study included interviewing 43 motorists downstream from the bridge. Sixty-five percent said that they had seen an ice warning sign.

Unpublished studies by 2 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 sign—REDUCE SPEED, ICE ON BRIDGE. Activation was provided by an ice detection system, and each of the messages was displayed alternately for 2 seconds at a time. Speed-check studies at the sign location, about 1 mile (1.6 km) from the bridge, showed 85th percentile speeds to be reduced from 65 to 35 mph (104.6 to 56.3 km/h) when the sign was activated. However, no information is available on either the novelty effect of the sign or its effect on 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 (before the point where the sign was readable) and on the bridge 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.

To assess the documented effectiveness of ice warning signs based on the reviewed studies, one should examine the common measures used and conclusions drawn. Subjective observations of sign effectiveness by Ballinger (1) and Stewart and Segueira (14) jointly establish that icy bridge signing should be responsive to the immediate hazard. A common inference from the 2 studies is that activated signing is necessary for desirable motorists' responses. Driver brake-light indications were used as a measure of sign effectiveness by Stewart and Segueira (14) and Glauz et al. (8). Both studies indicated that many motorists wait until they reach the bridge before they apply their brakes. As a tool to determine response to the sign the measure appears marginal, as evidenced by the 2 following points. Stewart and Segueira (14) show a significantly higher percentage of brake-light activation for poorer weather conditions.

Glauz et al. (8) point out that considerable speed reduction takes place without brake-light indications and that higher braking frequencies prevailed on certain days both with and without sign use. It appears from these 2 studies that brake-light applications are a response to environmental conditions rather than to signing.

Vehicular speed data obtained by Glauz et al. (8), Kentucky, and Arizona exhibit both conflicts and similarities. The most marked speed reductions were noted in the Kentucky study; however, because no data were collected at the bridge itself, the results are not compatible with the other 2 speed studies. The upstream and bridge observations of the Glauz et al. (average speeds) and Arizona (85th percentile speeds) studies are compared in Table 1. The data are similar in appearance, but the study conclusions conflict. Glauz et al. (8) found speed reductions at the bridge due to signing to be significant at the 0.01 confidence level. Although no formal statistical test was applied in the Arizona study, observed speed differentials 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 (10.78 km/h) observed at the bridge between signing conditions is similar to those recorded by Glauz et al. (8). The reviewed studies comprise virtually all available documentation examining motorists' responses to icy bridge warning signs. Because the efforts were aimed at remedying a severe hazard and provided conflicting results, it is evident that more research is needed.

DEVELOPMENT OF EXPERIMENTAL SIGNING

A review of the literature revealed a rather limited use of sign wording and formats to advise motorists of an icy bridge hazard. It was therefore apparent that further surveys should be conducted before designation of the specific signing to be used. Letters of inquiry were sent to numerous highway departments to seek out representative sign characteristics. Responses and information gathered during the literature review provided 24 different sign messages and a diversity of formats. They are shown in Figure 2. It was felt, based on the literature review, that activated signing would be more effective than nonactivated. However, after one considers the financial constraints 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 the preference rating of 20 subjects, some of whom were knowledgeable in highway sign design.

The signs shown in Figure 3 were selected for field evaluation. Primary sign characteristics studied were activation type and location. Eight combinations of the 4 signs were used at 2 bridge approaches to permit comparisons of activated and nonactivated signs, at-the-bridge and before-the-bridge locations, and short and long sight-distance approaches. All signs were displayed both singularly and in combination on both approaches.

The standard diamond 36-in. (91.4-cm) sign with 6-in. (15.2-cm) black lettering on yellow reflective backing was used. Activated advance signing had ICE steadily displayed in brightly illuminated, red, 6-in. (15.2-cm) letters. The activated sign at the bridge location used two 8-in. (20.3-cm) beacons flashing alternately at a rate of 50 times per minute. At-the-bridge and before-the-bridge signs were located 100 and 1,000 ft (30.5 and 305 m) respectively before the bridge.

SELECTION OF TEST SITES

Site selection involved seeking candidate sites that met certain criteria related to the bridge environment and traffic characteristics. The bridge had to represent a potential ice hazard. That is, it had to be in a region where the temperature frequently fell below freezing in winter. Certain other bridge characteristics that would enhance its ice-proneness were sought. The bridge had to be high enough to allow rapid cooling beneath the deck, and it had to be over water that flowed throughout the year. Also certain traffic characteristics were necessary for a meaningful evaluation of signing.

Table 1. Upstream and at-the-bridge speed observations.

	Glauz Study (mph)			Arizona Study (mph)
Location	Lane 1	Lane 2	Lane 3	All Lanes
Upstream				
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
Difference				
With sign	14.5	14.9	15.4	10.8
Without sign	8.4	6.8	9.3	7.5

Note: 1 mile = 1.6 km.

Figure 2. Characteristics of signs that 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 — 65 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 BRIDGE	Diamond, black on yellow	Static	Ohio	Mississippi, West Virginia, Indiana, Kansas Montana
WATCH FOR ICE ON BRIDGE	Diamond, black on yellow	Static		South Dakota
	Rectangular, black on yellow	Static		Virginia

Note: 1 in. = 2.54 cm. 1 mile = 1.6 km.

The bridge had to be on a well-traveled interregional route to obtain a sizable population of unfamiliar motorists in the early morning hours (maximum likelihood of preferential icing). However, the vehicle detection sensors that were used function best under low to moderate traffic volumes. Therefore, the desirable type of road was deemed to be a primary 2-lane route that had no parallel Interstate route.

Twenty candidate bridge sites in Virginia, West Virginia, and western Maryland were considered for inclusion into the study. The selected bridge was the US-340 bridge over the Potomac River, which is 2 miles (3.2 km) east of Harper's Ferry, West Virginia. This location is noted for frequent freezing temperatures because of its elevation. The bridge is 2 lanes, approximately 0.4 miles (0.64 km) in length, and about 40 ft (12.2 m) above the river. US-340 at that point has sufficient average daily traffic for data collection beginning at 6 a.m. and a suitable number of nonfamiliar motorists. Fortunately, the location was not affected by the reduction of speed limits imposed by the early 1974 energy shortage.

Two data collection sites were designated as the long sight-distance (westbound) and short sight-distance (eastbound) approaches. Another bridge on US-340 that crosses the Shenandoah River 2 miles (3.2 km) farther west 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. Because the eastbound approach on the control bridge was instrumented, the same motorist sample was used for testing experimental signing effects at the eastbound study site.

DATA COLLECTION PROCEDURES

Two primary data collection techniques were employed. Vehicle performance data were gathered by using the traffic evaluator system, and driver characteristic data were obtained by questionnaire. Figure 4 shows each technique.

The traffic evaluator system consisted of road sensors, manual code switches, and a digital tape recorder. The equipment was small, portable, and easily concealed. The system was a powerful data collection technique that allowed precise measurements of driver-vehicle behavior over large areas of highway. The traffic sensors (tape switches) were extruded plastic devices about $\frac{1}{8}$ in. (3.2 mm) high by $\frac{1}{2}$ in. (12.7 mm) wide. The tape switch was an unobtrusive sensor that caused little vibration and noise to a vehicle when it crossed it. The system allowed monitoring of all vehicles in lanes instrumented with the sensors. Associated with the traffic evaluator system was provision for manual code inputs. Thus, randomly selected vehicles were coded to be interviewed, and their speed data were matched with appropriate questionnaire responses.

Interviewing of motorists was conducted during the testing of all experimental signing conditions. Speed data for each vehicle were matched to questionnaire responses for analysis. Interview locations were beyond driver sight-distances from the speed sensors. In this way, unbiased speed data were obtained. Vehicles selected for motorists' interviews were those with sufficient headways that their speeds were not influenced by others in the traffic stream. An interviewing strategy was adopted that permitted certain driver characteristics data to be obtained before the drivers knew that the study related to potential skid hazard. After a brief introduction that advised the motorists that a safety study was being conducted, general questions were asked to derive their familiarity with the site and the level of their driving practice. More specific questions were then asked regarding their assessment of safe speed during possible icing conditions and whether the bridge was always sanded when icy. By this time, the motorist knew the study pertained to potential skidding. The driver was then asked whether the bridge was a potential hazard and, if so, what their cue of the hazard was. In cases in which the experimental sign was not cited as the cue, the drivers were asked if they had seen a warning sign. If they had, they were asked to identify the sign by describing its appearance and message and to rate the sign as being helpful or not helpful.

Figure 3. Icy bridge warning signs that were evaluated.

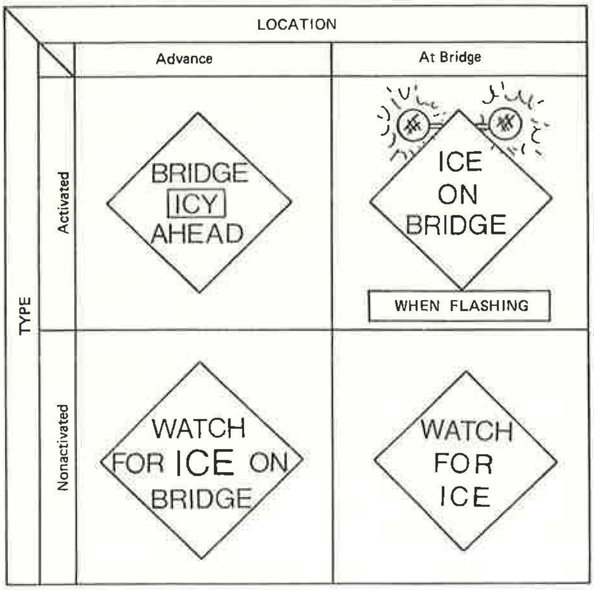
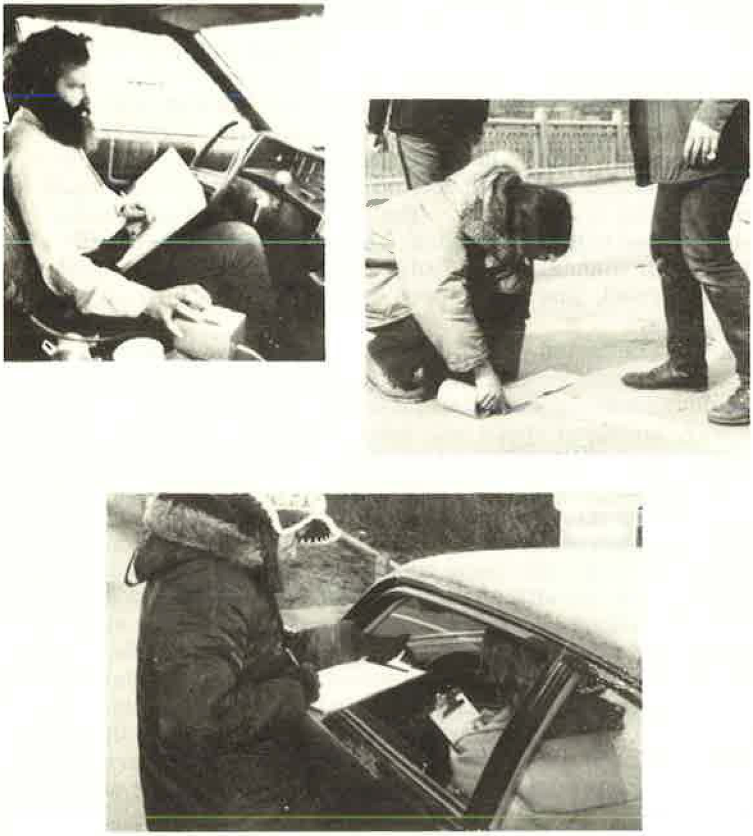


Figure 4. Traffic evaluator system and interviewing.



ANALYSIS OF SPEED DATA

Two approaches to the bridge were used to gather data revealing motorists' responses to the series of warning signs. One approach was characterized by long sight-distance and the other was characterized by short sight-distance. Data were collected on each approach at distances of 1,200 and 600 ft (365.8 and 182.9 m) from the bridge, at the bridge entrance point, and on the bridge at a distance of 150 ft (45.7 m) beyond its entry point. Two sign locations were studied: at-the-bridge [100 ft (30.5 m) before the bridge] and before-the-bridge [1,000 ft (305 m) before the bridge]. Both activated and nonactivated signing were tested during daylight hours and periods of predawn darkness. Ambient conditions were conducive to preferential bridge icing, and frost occurred 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 conduct interviews.

Experimental sign conditions consisted of the signs shown in Figure 3 (singularly and in combination). Eight schemes were used to determine the effects of activation type and sign location. One day's baseline data were gathered on each bridge approach to permit a sign versus no sign comparison for all experimental sign conditions. Times of data collection were 2 hours before sunrise and 2 hours after sunrise.

Westbound Approach

Motorists' responses to signing in the long sight-distance approach were generally not as favorable as those later observed on the short sight-distance approach. Two reasons 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 roadway shoulders necessitated a substantial lateral displacement of the signs. Second, the bridge itself was a major competitor for motorists' attention as it came into view before their reaching the advance sign.

An attempt to compare the effects of all signs is shown in Figure 5. An hour-for-hour comparison of each experimental signing condition and its corresponding time period in the baseline data reveals the relative effects of each signing condition. This figure shows mean speed differences ranked so that the most effective signing condition is at the top; statistically significant reductions are indicated. The result is somewhat suspect in that reductions in mean speed were noted for most signing conditions, which is unlikely and contradicts effects that have been shown in the literature. It is 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 an activated, at-the-bridge sign used in combination with a nonactivated, before-the-bridge sign. Promising effects are also evident from other activated signs used singularly and in combination with nonactivated signs. The combination of activated signs at both locations did not perform well during daylight hours. Questionnaire results confirm that fewer motorists saw signing during daylight hours.

To verify or refute the cited differential effects, a more detailed examination was made of the driving samples. Figures 6 and 7 show plots for darkness and daylight observations of mean speeds for both the total and highest quartile samples. Generally, high speeds at the 600-ft (182.9-m), before-the-bridge 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 before-the-bridge signing.

Interesting contrasts can be noted in the behaviors of the 2 samples, especially during hours of darkness. Although total-sample mean speeds were generally lowest at the bridge approach, the highest quartile group was still decelerating as it reached the bridge. The faster motorists exhibited greater variability in speeds as they reached the bridge, the greater were their overall approach decelerations, and they generally exhibited greater differential decelerations in response to various signing

Figure 5. Effects of all signs.

Advance Location	At Bridge	Ambient Condition	Speed Reduction	
			Bridge Entry	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

Note: 1 mile = 1.6 km.

*Significant reduction from normal condition: a < 0.05.

Figure 6. Mean speeds during predawn hours on the long sight-distance approach.

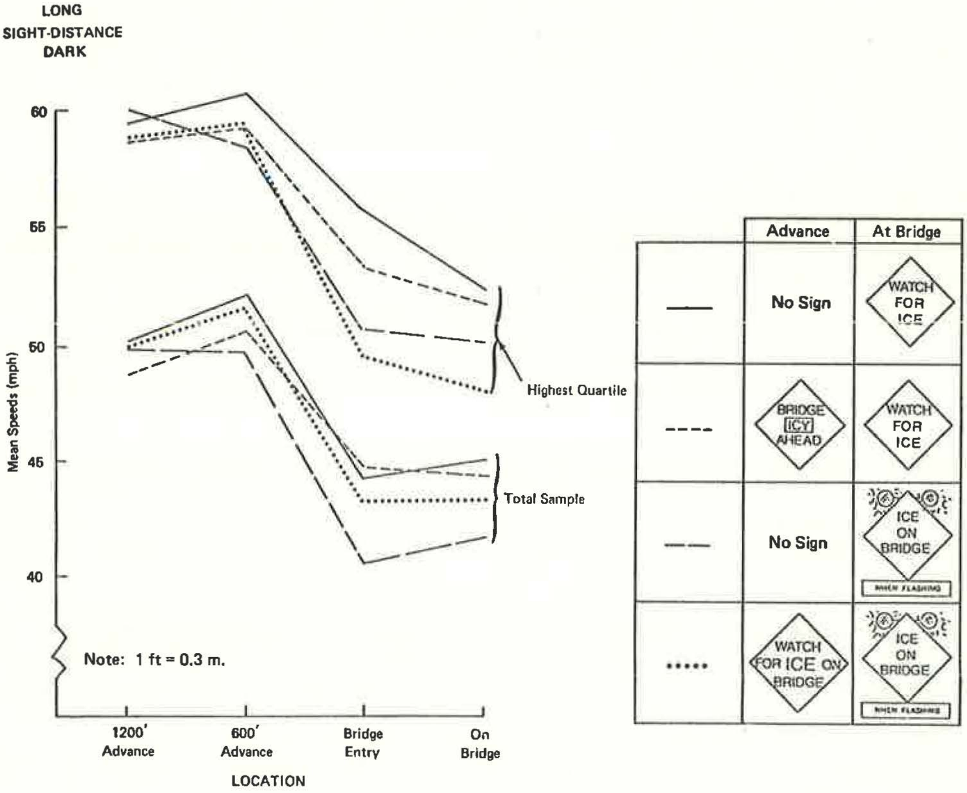


Figure 7. Mean speeds during daylight hours on the long sight-distance approach.

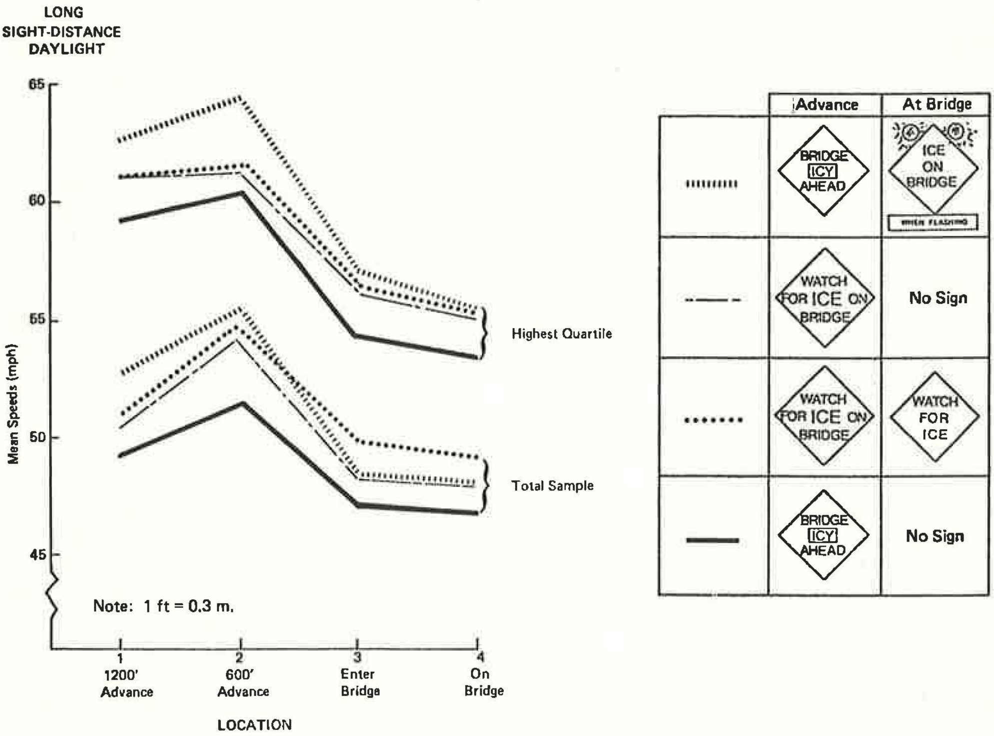
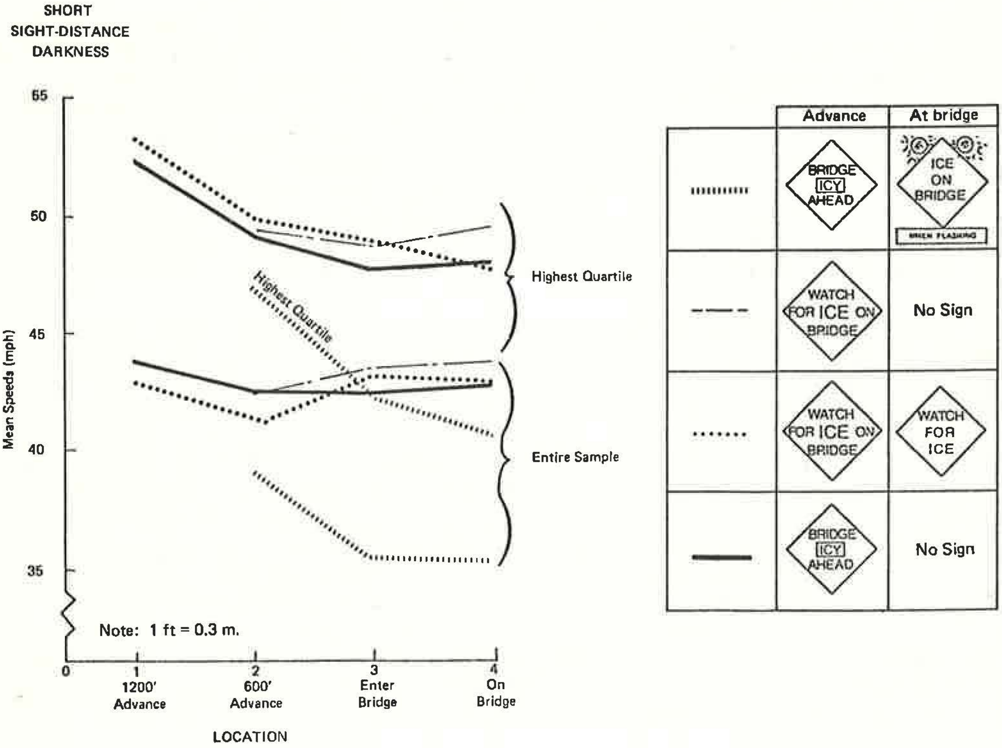


Figure 8. Mean speeds during hours of darkness on the short sight-distance approach.



conditions. The sharpest approach decelerations were observed in response to the activated sign located at the bridge during hours of darkness.

Certain inferences relating to signing effects can be gained from the data shown in Figures 6 and 7. Lowest speeds were obtained in response to 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, before-the-bridge sign performed well when it was displayed by itself. But direct speed comparison is not the best effectiveness measure in this case because of possible day-to-day variations that could not be accounted for because no control site was available. To eliminate spurious effects, a final judgment of results is based on overall speed reductions obtained for each sign between the 1,200-ft (365.8-m), before-the-bridge location and the bridge during each condition of darkness and daylight. The 2 signing schemes that gave the best performance were the at-the-bridge sign activated by itself and the combination of activated signs at both locations.

Eastbound Approach

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 2 miles (3.2 km) upstream on US-340. The identical approach geometry of the 2 bridges created a well-suited experiment site pair. Because 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.

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

Control site data were limited to the bridge entry location because it was the most critical point at which to examine motorists' sign responses. Direct speed comparisons were made between bridge entry points of the 2 sites for sign evaluation purposes because 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. Observed values show that the use of 2 activated signs results in 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 at-the-bridge, activated sign. This confirms its observed result on the long sight-distance approach.

After comparing bridge approach speed data on an hour-for-hour basis, I noted 3 expected findings: (a) activated, before-the-bridge signing produced significantly greater speed reduction than did nonactivated, before-the-bridge signing; (b) 2 activated signs produced better results than did nonactivated signs; and (c) for activated and nonactivated signs used together, activation of the at-the-bridge sign produced better results than did activation of the before-the-bridge sign. Findings a and b were observed during conditions of darkness, and finding c was observed during daylight. These observations were based on mean speeds for the total vehicle sample. Keep in mind that the fastest motorists are most suitably designated as the target sample. Figures 8 and 9 provide mean speed plots for both the total and highest quartile samples. Data are somewhat incomplete because the 1,200-ft (365.8-m) before-the-bridge tape switch failed to adhere to the pavement on 1 morning. However, the lost data did not prove to be critical. Most notable in Figure 8 is the extreme speed reduction resulting from use of activated signs at both before-the-bridge and at-the-bridge positions. Ambient conditions were highly conducive to such a response to the

Figure 9. Mean speeds during daylight hours on the short sight-distance approach.

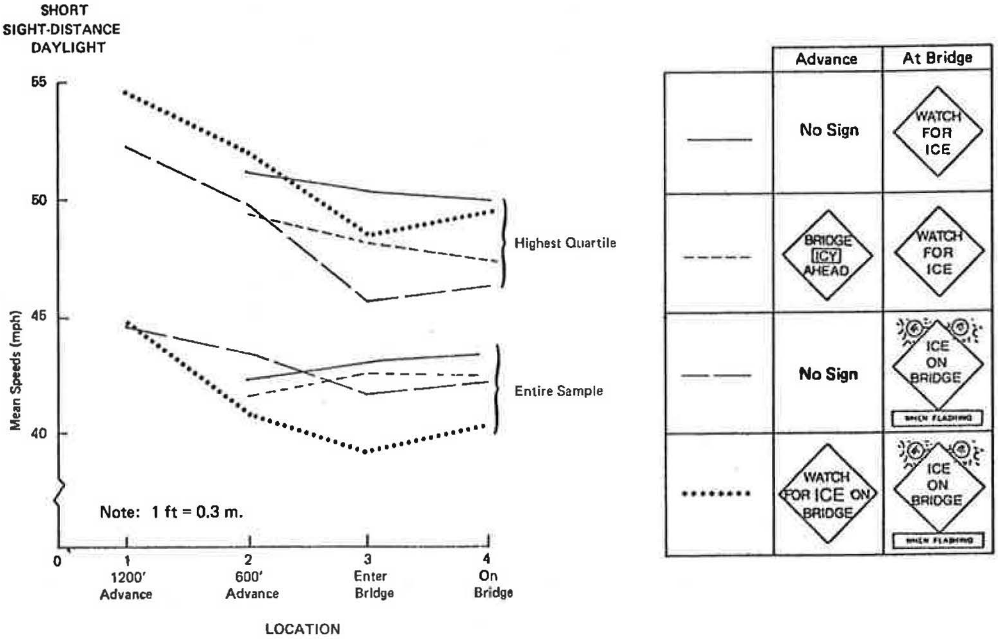
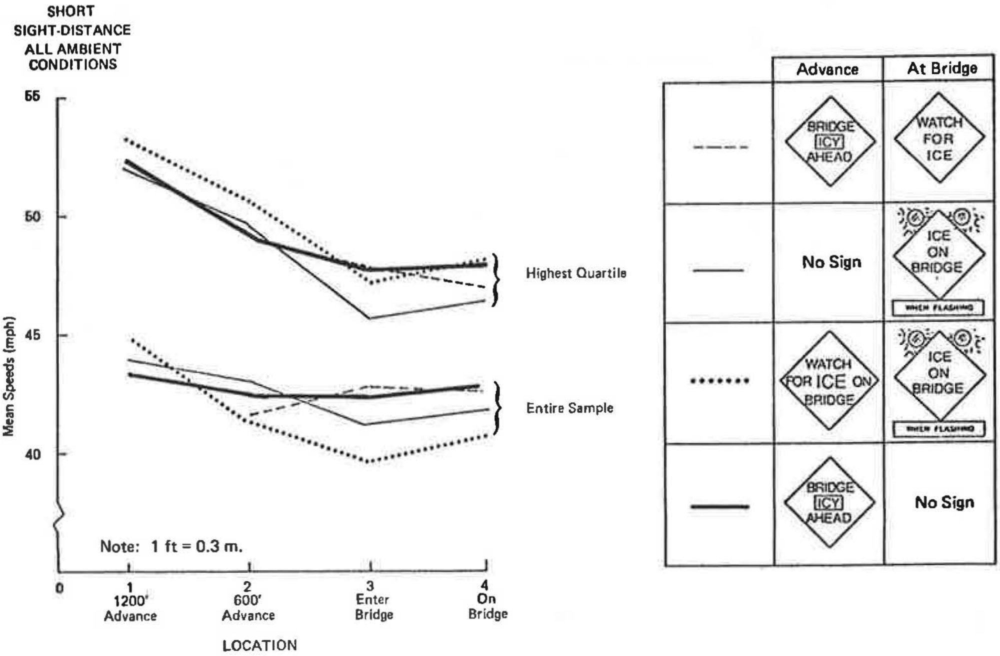


Figure 10. Adjusted mean speeds for all signing conditions with 1 activated sign.



signing. Their conspicousness was increased during darkness, and their perceived credibility was enhanced by the occurrence of moderate frost. Further note must be made of concurrent speeds at the control site, which had no signing. Observed higher-than-average speeds, representing a slight increase from the preceding hour, indicated 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; the nonactivated before-the-bridge sign afforded the lowest speed reduction. In fact, average speeds for the total sample increased at the bridge approach during use of both nonactivated signing schemes. The highest quartile motorists slowed slightly for the nonactivated advance sign, but then they increased speed. The combination of 2 nonactivated signs caused continual slowing on the part of the highest quartile motorists, yet speeds remained high. The activated before-the-bridge sign did cause motorists to slow down but to an insignificant degree compared to both nonactivated signs.

Response to signing under daylight conditions (Fig. 9) shows the poor results obtained with the nonactivated sign. Better results generally were obtained with the at-the-bridge, activated sign rather than with the before-the-bridge, activated sign. The single exception is the highest quartile response to the at-the-bridge, activated sign used together with the nonactivated warning.

In view of the criticality of distinguishing between the relative merits of activated signs located at the bridge and before the bridge (because of the cost of providing both), we took a further analytic step. Figure 10 shows 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 speed effects. As seen from the figure, closer groupings were obtained for both average and highest quartile speeds. Lower bridge entry speeds were observed for both the average and highest quartile speed samples with the use of at-the-bridge, activated signing rather than with before-the-bridge, activated signing.

Speed Data Results

In all compatible instances, activated signing elicited greater speed reductions than did nonactivated signing. Of the nonactivated signing observed, the WATCH FOR ICE ON BRIDGE sign before the bridge provided better results than did 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 before-the-bridge and at-the-bridge locations during hours of darkness. At-the-bridge, activated signs elicited larger speed reductions than did before-the-bridge, activated signs during both daylight and darkness.

QUESTIONNAIRE RESPONSES

Motorist reaction to both the hazard and experimental signing was examined through a regression analysis of data obtained from 168 questionnaires.

Signing Type

Activated and nonactivated signs were tested at each site for 2 approach locations: at the bridge and 1,000 ft (305 m) before the bridge. The effects of each type, location, and combination were studied. Because activated signing was found to have a greater effect on motorists, specific attention was given to the effect of its location. The advantages of activated over nonactivated signing were seen through correlations obtained among numerous variable-pair comparisons. At both sites, the use of activated signing increased the tendency for motorists to (a) see the signing, (b) notice both signs when 2 were displayed, and (c) properly identify both the sign's appearance and wording. Motorists were more prone to acknowledge the possibility of bridge icing when at least 1 activated sign was displayed. Because the data were collected during periods of virtually dry pavements, an inference from this last finding is that motorists would be more aware of icing possibilities when activated signing serves as a reminder. A comparison of those signing schemes incorporating before-the-bridge signs and those incorporating at-the-bridge signs showed no significant differences with respect to any questionnaire variables.

Ambient Condition

Two ambient condition comparisons revealed an effect on driver responses of icy bridge warning signs. Effects of daylight versus darkness and dry pavements versus light frost were notably different.

Darkness

During hours of darkness, a significantly higher proportion of interviewed motorists reported seeing the signs and properly identified their appearance and wording. The increased conspicuousness of activated signing because of darkness was undoubtedly responsible for the difference because no significant change in the nonactivated sign observation rate was noted.

Frost

During periods of light frost more motorists acknowledged the possibility of ice formation on the bridge. The motorists' cue of frost was predominantly its accumulation on their windshields.

Sign Observation

Significant increases in the proportions of motorists observing signs were noted with the use of activated signs. Improved responses were obtained when the activated sign was located at the bridge rather than before the bridge. 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 signs. Those motorists who noticed the signs were more likely to acknowledge the possibility that ice might be on the bridge. Greater speed reductions and lower overall speeds were observed for drivers at both sites who had observed the signs. Highest observation rates were obtained for the ICE ON BRIDGE—WHEN FLASHING sign at the bridge.

Observation of Both Signs

When there were 2 signs, data were maintained on which of the signs was observed by motorists. Motorists were more likely to see both signs for conditions when at least 1 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 1 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 non-activated signs, and their performance improved during hours of darkness. Drivers who properly identified a sign's 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.

Proper Identification of Sign Wording

Motorists were more likely to properly identify the wording of activated signs, 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 1 site, wording was more often correctly identified by older drivers. The sign correctly identified most often was the WATCH FOR ICE—WHEN FLASHING activated sign located at the bridge.

Driver Characteristics

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

Familiarity With Site

A greater proportion of familiar motorists was observed at both sites during hours of darkness because of 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 than did unfamiliar motorists, and they maintained lower speeds as they continued on the bridge.

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.

Knowledge of Bridge Maintenance

Motorists were asked if they knew whether the bridge was salted or sanded when it was icy. The intent was to ascertain the effect on the speeds of those drivers who were confident of maintenance activity, but no speed differences were observed. Those motorists with more driving practice felt that the maintenance was not regularly performed. Drivers who felt that the bridge would probably not be sanded were more prone to observe both signs when 2 were displayed.

Driving Practice

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

Assessment of Possible Icing

Because interviewing was conducted during marginal occurrences of 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 2 activated signs were displayed. 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 because more acknowledgments were noted during predawn hours and during the presence of frost.

Those drivers who acknowledged the possibility of bridge icing exhibited lower speeds throughout the array of speed data collection points. The most notable speed reductions at both sites occurred at the bridge entry location—the critical slowing point for motorists concerned about bridge icing. The second highest speed reduction occurred on the bridge, which confirmed the motorists' concern about bridge icing. That signing was largely responsible for the speed reductions of those motorists who suspected bridge icing is 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 tape switch pair on the short sight-distance approach where the at-the-bridge warning sign was not visible.

Age

The mean age for motorists at both sites was 41. 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-ft (365.8-m) before-the-bridge location on the short sight-distance approach. Another finding that confirms that younger drivers have less regard for the icy bridge hazard is that they were significantly less likely to recognize sign wording at 1 site.

Sex

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

SUMMARY AND FINDINGS

An examination of 8 experimental signing combinations made up of activated, nonactivated, before-the-bridge, and at-the-bridge signs was conducted at 2 bridge approaches. Activated signing elicited greater speed reductions than did nonactivated signing. The sign condition eliciting the maximum speed-reducing effect consisted of activated signing at both before-the-bridge and at-the-bridge locations during hours of darkness. At-the-bridge, activated signs elicited larger speed reductions than did before-the-bridge, activated signs during both daylight and darkness.

Motorist interviews were used to expand and clarify reactions 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 lower speeds on the bridge and its approach. Better overall responses were elicited by activated signing located at the bridge rather than 1,000 ft (305 m) before the bridge. Activated warning signs were effective as a hazard cue because more drivers acknowledged the possibility of bridge icing when activated signs were displayed whether frost was present or not.

Two sign conditions employing activated signing produced promising results and are recommended for further study based on field observation at other locations to establish the general nature of these results. The sign scheme eliciting the best response was an activated, BRIDGE ICY AHEAD sign 1,000 ft (305 m) before the bridge together with an 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-ft (305-m) before-the-bridge location. The effectiveness of the signing would be dependent on a reliable ice detection system for its activation.

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