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Subject Areas

51	Highway Safety
53	Traffic Control and Operations

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CONTENTS

FOREWORD

The authors whose papers are presented in this RECORD have addressed their research to several aspects of the satisfaction of motorists' needs for information. In an ever-increasing variety of highway environments, designs, and regulations, it becomes more important that motorists be able to determine quickly and without error what maneuvers they are required to make to navigate through the system safely, efficiently, conveniently, and comfortably. Ambiguity of information, confusion, and misinterpretation are factors that lay the groundwork for system failures. Those responsible for the design of information sources need to know the manner in which drivers demand information to resolve uncertainty and the form the information should take to yield the most rapid, error-free processing by motorists. The 8 papers in this RECORD are worthy additions to the designer's store of knowledge on motorist information systems.

The paper by Farber and Gallagher describes an experiment in which drivers wearing goggles with various density filters were required to negotiate a slalom course. Varying vehicle speed and goggle filter density, the researchers measured attentional demand. They conclude that attentional demand provides a measure of control task difficulty or operator skill to which more conventional measures may be insensitive.

Bleyl reports a study designed to evaluate an in-vehicle display that would give drivers advance information of the signal indication at an approaching intersection. Travel characteristics and speed profiles as measured by buried detector loops were used to measure the utility of advance signal information. He finds that a dynamic in-vehicle display increases the smoothness and safety of vehicle speeds at a signalized intersection.

Sign graphics is the subject of 4 papers. Dewar and Swanson investigated word versus symbol messages related to turn restrictions. Both field and laboratory techniques were used.

Eberhard and Berger undertook an extensive laboratory study of diagrammatic guide signs. Emphasis was placed on deriving guides for sign designers. The study shows that better driver performance at certain types of interchanges is permitted by diagrammatic signs than by conventional signs.

Gordon reports a laboratory study designed to replicate the findings of the Eberhard-Berger research mentioned above. Using similar, but not identical laboratory techniques, Gordon's work shows that conventional signs are superior to diagrammatics at all interchange types tested.

Field-testing of diagrammatic signs in New Jersey and Virginia is the subject of 2 papers.

Roberts used television surveillance to collect data on erratic maneuvers on I-287 at its interchange with US-22. He concludes that a significant reduction in erratic manuevers resulted from the erection of diagrammatic signs.

Hanscom studied the effect of a single diagrammatic on a complex interchange on I-495 in Virginia. After erratic maneuvers were classified by type, before-and-after data were collected. The results are discussed in terms of reduction of erratic maneuvers by type, and general conclusions are drawn from the entire study.

Heathington and Urbanik report a survey of 259 Indiana drivers used to determine how drivers perceive the relative hazard of highway-railway grade crossings and what their preferences are for the kind of warning that could be used. The researchers found that changeable-message signs were the most preferred of all other devices and passive (static) signing was the least preferred.

—Gerson J. Alexander

ATTENTIONAL DEMAND AS A MEASURE OF THE INFLUENCE OF VISIBILITY CONDITIONS ON DRIVING TASK DIFFICULTY

Eugene Farber and Vincent Gallagher, Franklin Institute Research Laboratories, Philadelphia

Six drivers were required to negotiate a slalom course at an automatically controlled speed (30 or 45 mph) while wearing goggles fitted with various neutral-density filters and a motorcycle helmet with a gas piston-operated translucent face shield. The face shield could be moved from its normally occluding position for a ½-sec "look" by means of a foot switch accessible to the driver. Attentional demand as measured by frequency of looks increased significantly with increasing goggle density at both 30 and 45 mph. The effect of the goggles on attentional demand was stronger at 45 than at 30 mph and for frequently looking than for infrequently looking subjects. Within subjects (error) variability was very low. Other measures of performance were not influenced by the goggles. It was concluded that attentional demand provides a measure of control task difficulty or operator skill to which conventional measurements may be insensitive.

•THE PURPOSE of this experiment was to evaluate the vision interruption apparatus (VIA), developed by Senders (2), as a method of measuring the sensitivity of drivers to degraded visibility conditions in steering and control tasks. The VIA consists of a helmet with a movable translucent face plate that can be controlled to periodically interrupt the driver's vision. A recent review of the literature (1) has revealed no data demonstrating a relation between night visibility conditions and driver steering-tracking performance measures. This is not surprising for it is frequently difficult in tracking tasks to demonstrate an objective decrement in performance in response to degraded operating conditions. This is especially true where the basic control task is undemanding. In such cases, it is presumed that the operator compensates for degraded conditions or increased task difficulty by attending more intently to the control task, with the result that his output remains constant under a wide range of conditions. Under more difficult conditions, however, a driver is closer to the limits of performance and is presumably less able to respond to sudden increases in task load.

Attempts have been made to measure "spare capacity" or its complement, "attentional demand," by means of subsidiary tasks. However, this approach has not been generally successful in driving research. A direct measure of attentional demand is provided by the VIA. In experiments with the VIA the driver, under instructions to look as infrequently as possible, determines his own visual sampling rate by controlling the movement of the face shield with a foot switch. In earlier research, Senders (2, 3) demonstrated that attentional demand, defined in terms of looks per unit time, depended on the apparent difficulty or complexity of the driving task.

In the present study, the VIA was used to obtain a measure of the attentional demand associated with degraded visibility conditions roughly approximating poor nighttime highway lighting conditions. The study was performed during the day, and the degraded visibility conditions were produced by goggles with neutral-density filters. The light-

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reducing goggles do not produce for the viewer a scene that is phenomenologically equivalent to the normal nighttime scene; they do, however, produce a qualitatively similar degradation of visibility.

METHOD

Test Vehicle

The test vehicle was a 1970 Plymouth Fury 440 equipped with power steering, power disk brakes, automatic transmission, 380-hp engine with 440-in.^{3} displacement, and a speed-control device. The speed-control device when activated at a given speed will maintain that speed to within 2 mph. The car was instrumented to record time, speed, distance, lateral acceleration, and VIA face-shield activations, i.e., "looks."

Visual Interruption Apparatus

The VIA consists of a motorcycle helmet whose face shield can be moved up or down by means of a gas-operated piston mounted on the helmet. The piston is activated by a solenoid valve whose switch is accessible to the driver's left foot. The shield was spray-painted to render it translucent. During testing the normal position of the shield was down (the occluding position). Depressing the solenoid switch drives the helmet to the up (seeing) position for ½ sec during which time the switch is inactive. To obtain repeated looks, the driver must wait for the helmet to return to the down position before depressing the switch again. As a safety measure, an up switch was incorporated into the horn ring. Depressing the horn ring drives the shield to the up position and locks it there. The experimenter's control unit also incorporated a safety switch to lock the shield in the up position.

Goggles

The illumination reaching the driver's eye was varied through the use of neutral-density filters (Eastman Kodak 96, 3-in. gelatin) cut to fit the 50-mm lens hole of Bausch and Lomb S-84P goggles. These goggles have opaque side panels and can be adjusted for a snug fit with no light leaks. The 3 densities of the filters were 0.0 (100 percent transmittance), 2.6 (0.25 percent transmittance), and 3.6 (0.025 percent transmittance). The actual transmittance values were probably about 10 percent less than the nominal values, but the difference was not felt to be important.

Test Site

The tests were conducted in the northbound direction of a 1.4-mile unopened length of I-95 in Philadelphia. The roadway (3 lanes and shoulders) is 48 ft wide. Ambient illumination in the direction in which the trials were run was consistently around 1,000 ft-C. A course consisting of four 0.10-mile long traffic-cone slaloms was set up with 0.10-mile separations between slaloms. Each slalom consisted of five 2-cone gates.

Subjects

Six test subjects were used. All were men under 30 years of age. Three were college students, and 3 were technicians employed at the Franklin Institute. All claimed to have 20/20 vision, but this was not verified.

Procedures

The subject's task was to drive the slalom course at an automatically controlled speed without hitting any of the traffic cones. Subjects were told that they would receive bonus pay for good scores and that a good score depended on both minimizing looking time and not hitting any traffic cones. Prior to the start of formal testing, each subject had 5 practice trials without the goggles to familiarize himself with the course, the car, and the operation of the VIA. During formal trials, subjects wore the goggles fitted with neutral-density filters and the VIA helmet. Subjects were permitted to adapt to the higher density goggle conditions for 30 min before the start of trials with those goggles. At the start of a trial the subject accelerated to the assigned speed for that trial and then activated the speed-control device. He then negotiated the slalom course by using the foot switch to obtain ½-sec looks as required.

Experimental Design

Each subject had 4 replications of each of 6 speed-goggle combinations for a total of 24 trials. There were 2 speeds (30 and 45 mph) and 3 goggle conditions as described above. For each driver, speeds were alternated from trial to trial in the order of 30-45, 45-30, and 30-45. Order of presentation of goggle density was partially counterbalanced. Three of the 6 subjects had condition 3 first, one had condition 1 first, one had condition 2 first, and one had only conditions 2 and 3 in that order.

RESULTS AND DISCUSSION

Figure 1 shows the mean percentage of looking time (attentional demand) for each subject at 30 and 45 mph as a function of goggle density. Percentage of looking time is given by

$$P = (N/2T) \times 100$$

where N is the number of ½-sec looks and T is the total time of the trial. Table 1 gives the results of an analysis of the variance of these data. All of the main effects and all of the 2-way interactions were significant. Attentional demand increases with increasing goggle density and is greater at 45 than at 30 mph. Also there were large and consistent differences between subjects. The effect of the goggles was clearly more pronounced at 45 than at 30 mph and for frequently looking than for infrequently looking subjects. Further, the more frequently looking drivers were more affected by speed. Although there was increase in the percentage of looking time from 30 to 45 mph, the increase was less than would have been obtained had looks per unit distance been the same at the 2 speeds.

A striking feature of the results was the extremely low error variability; although there were large and reliable differences among subjects, the performance of individual subjects was highly consistent under a given set of conditions. Further, the ordering of the subjects changes little across the speed and goggle conditions as reflected in the low 3-way interaction term.

The goggle conditions had no effect on 2 other performance measures: "smoothness," as measured by peak lateral acceleration values, and frequency of traffic-cone knockdowns. In fact, only 1 traffic cone was struck during the entire course of the experiment. Figure 2 shows mean peak lateral acceleration as a function of goggle density for the 4 subjects on whom lateral acceleration data were obtained. The mean peak acceleration value was obtained for a given subject and set of conditions by averaging across replications the peak lateral acceleration values associated with the same slalom gate. Because the speed was automatically held constant during a trial, the peak lateral acceleration value is almost solely a function of path and is taken as a measure of smoothness. Neither at 30 nor at 45 mph was there any systematic relation between lateral acceleration and goggle density. However, the 2 subjects who had the highest lateral acceleration scores (RD and WS) also had the highest attentional demand scores.

These findings suggest that, for a given driver, attentional demand is a reliable indicator of task difficulty as mediated by visual conditions and that, on a given task, attentional demand scores reflect driver skill. In these terms the results can be summarized by saying that visual degradation increased the difficulty of the vehicular control task but that the more skilled drivers were less affected.

CONCLUSIONS

The results of this experiment indicate that, by quantifying attentional demand, the VIA provides a measure of visual task difficulty to which conventional performance

Figure 1. Looking time as a function of goggle transmittance.

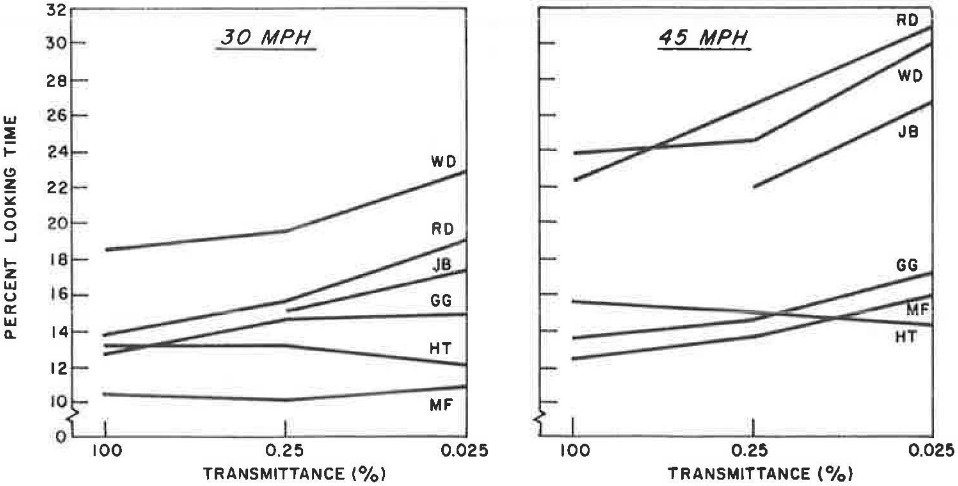

Figure 2. Lateral acceleration as a function of goggle transmittance.

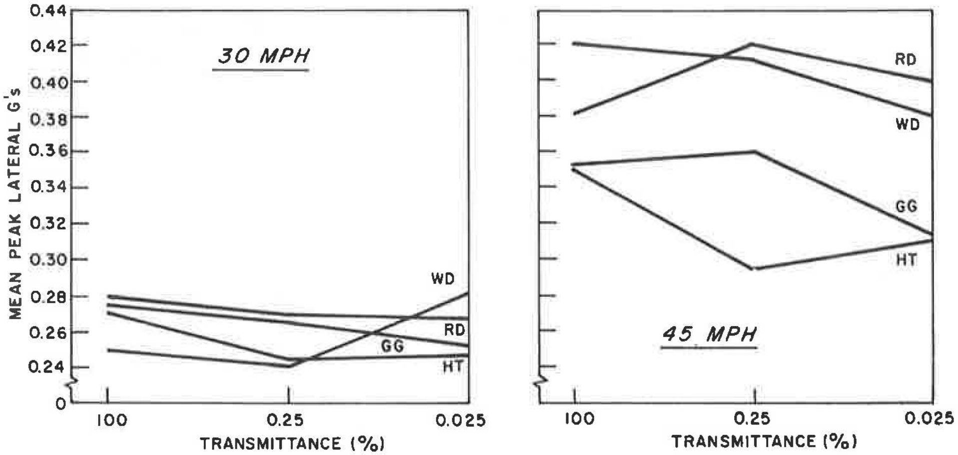

Table 1. Analysis of variance.

Source	SS	df	MS	F
Subjects	2,327	4	582	183.01
Goggles	205	2	103	32.38
Velocity	666	1	666	209.43
Subjects × goggles	162	8	20.25	6.36
Subjects × velocity	339	4	85	26.7
Velocity × goggles	26	2	13	4.09
Subjects × velocity × goggles	11	8	1.4	0.44[a]
Within	286	90	3.18	—
Total		119		

Note: Data for subject J.B. not included in analysis of variance.

[a] Not significant.

measures may be insensitive. More generally it is felt that the concept of attentional demand, as measured by the VIA or similar device, is applicable as a basic measuring tool to any research in which driver performance provides the criterion measure. In particular, the results of this study indicate that the VIA can be used to measure the influence of night visibility conditions on the difficulty of the driving control process.

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DISCUSSION

Frederick Lehman, Newark College of Engineering

The authors conclude that their tests have demonstrated (a) that the VIA provides a measure of visual task difficulty and (b) that it provides a basic measuring tool for determining the loading effects of certain physical conditions on driver performance. Going one step further, this technique could provide a standardized measuring tool for comparing the difficulty of various driving tasks that relate strongly with attentional demand, e.g., traffic situations.

There are a few points that deserve special comment. There is the general problem of working with conditions that are both realistic and meet the experiment's requirement of having the drivers operate with some spare capacity in performance response. The authors say very little about the design of the experiment as it relates to this problem.

In connection with real roadway nighttime lighting conditions, it can be shown how the conditions used in the experiment relate to design requirements. The values listed below show that lighting conditions are roughly equivalent over a wide range.

Roadway	Design Illumination Range (ft-c)	Experiment Transmittance (percent)	Perceived Illumination (ft-c)
Local urban-major urban	1.0-2.0	0.25	2.5
Minor residential-rural freeway	0.2-1.0	0.025	0.25

From the fact that the low illumination condition (0.025 percent) is close to the recommended safe lower design limit (minor residential), it can be inferred that this condition used in the experiment represents a safe approach toward the lower limit of driving visibility.

Two results of the work point out that the subjects in fact were not operating close to their performance limits. First, an increase in speed did not require any increase in the number of looks. Second, extremely few cones were knocked down.

On the effect of velocity, it would seem that some further comments can be made. When based on the number of looks for the given distance of the course, there is no significant difference between the average obtained for the runs at 35 mph and that for 45 mph. Therefore, issue is taken with the authors' statement that attentional demand is greater at 45 mph. Their results show that total demand for both speeds is equal.

This difference in interpretation raises a related question. How does the ½-sec look compare with attention spans during various driving tasks? Some insights on this question might be gained by varying the length of the look from ½ sec.

IN-VEHICLE DRIVER AID AT TRAFFIC SIGNALS

Robert L. Bleyl, University of New Mexico*

A full-scale working model of a communications system was developed and employed in an empirical study to determine whether an in-vehicle driver aid could assist automobile drivers in making a smoother and safer approach to a traffic signal installation. The driver aid informed drivers that they were approaching a signalized location and gave them information about the signal indication that they would encounter on their arrivals at the traffic signal. It was determined from this analysis that the smoothness and safety of travel approaching a traffic signal installation could be improved by the use of a personal, dynamic, in-vehicle display. Even though drivers knew ⅓ mile in advance when they would be stopped by the traffic signal, they adjusted their speeds gradually and generally refused to travel at speeds that seemed to be unnaturally slow. A combination auditory and light display, activated approximately 500 ft in advance of the signal and having a personal, binary message (prepare to stop or plan to proceed), was recommended for further development.

•**THE OPERATION** of a motor vehicle on today's streets and highways is a complex and demanding task. It has been estimated (1) that the average driver comes upon 10 or more traffic events and makes 2 or more direct observations per second. Even the best drivers occasionally overlook conditions and make errors. These oversights and errors sometimes result in traffic accidents.

An analysis of highway traffic accident locations will reveal the fact that intersections having high accident experience are often controlled by traffic signals. Further detailed analysis of traffic accidents at signalized locations will show 1 of 2 conditions associated with most of these accidents: (a) The driver of a motor vehicle did not see the signal in time, or (b) the driver of a motor vehicle responded to the signal or to a change in the signal indication either too quickly or too slowly for other traffic. Faulty driver perception has been identified as the root cause of many traffic accidents (2).

Traffic signal control, as it now exists, has numerous shortcomings that an increased level of uniformity will not be able to overcome. The limitations of today's traffic signals include the following:

1. The signal indications are not consistently displayed in the same position through the windshield, so the driver must constantly scan his field of view to find traffic signal displays;
2. The changes in signal indications are abrupt, and drivers frequently find it necessary to decelerate at higher than desirable rates;
3. The unpredictable nature of the signal indications encourages drivers to watch the signal instead of watching other traffic;
4. The view of the traffic signal display is sometimes blocked or camouflaged (large trucks, a low sun, fog, and colored advertising or Christmas lights at night all tend to obscure the visibility of the signal indication); and
5. The detection of the traffic signal depends exclusively on only one channel of communication—the visual sense—and that sense is more heavily loaded during driving than are any of the other senses.

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*When this research was done, Mr. Bleyl was associated with the Bureau of Highway Traffic, Pennsylvania State University.

In the consideration of possible solutions to the limitations inherent in present traffic signals, a suggestion was made to apply electronics to link the traffic signals with approaching vehicles in such a way that a driver could know in advance that he was approaching a signalized location and exactly what the signal indication would be on his arrival at the signal.

It was hypothesized that the advance, in-vehicle display of traffic signal information would overcome many of the present shortcomings of traffic signals and permit drivers to approach a traffic signal in a safer and smoother manner than would be possible without such information. With an in-vehicle display, traffic signal information would be displayed in one consistent location where drivers could always find it. Impending changes in signal indications would be communicated to drivers well in advance of the signal location. Prior knowledge of the signal indication to be encountered on arriving at the signal location would enable drivers to give more attention to other vehicles and pedestrians. Large trucks and other temporary view obstructions of the traffic signals would no longer be a problem. Both auditory and visual signals could be employed in the display.

A research project was undertaken as a pilot study at one signal location to determine whether the in-vehicle driver-aid concept was worthy of further research and development. The specific objectives of the project were to determine whether a personal, dynamic, in-vehicle display could aid automobile drivers to make smoother and safer approaches to traffic signals and, if so, what type of display information would be most effectively utilized by the drivers (3). One auditory and 2 visual displays were examined in this project.

As a result of this study, it was found that a personal, dynamic, in-vehicle display did aid an automobile driver to make a smoother and safer approach to the signal, especially when the signal indication to be encountered was red. Of the 3 displays examined, the light display, which resembled the real traffic signal, was most effectively utilized by the drivers.

STUDY DESIGN

The study was undertaken by observing the movement of drivers whose vehicles had been equipped with the 3 displays as they approached an actual traffic signal under real driving conditions. A traffic signal was installed and supplemented with the necessary detection, computation, and telemetry systems to operate the various displays mounted in the vehicles of selected test drivers.

The traffic signal was installed at a rural, right-angle, 4-way intersection in central Pennsylvania. The speed limit on the intersecting roadways was 55 mph. One approach to the signal was selected as the test site. Fourteen detector loops were installed at 150-ft intervals along the approach. The first loop was located 1,800 ft in advance of the intersection; the thirteenth loop was located at the intersection in line with the near right-of-way line of the crossroad; the fourteenth loop was located beyond the intersection. Detector signals were relayed by cable to a remote-control location. Advance visibility of the traffic signal was limited by a change in grade near the fifth loop, a point approximately 1,200 ft in advance of the intersection. Figure 1 shows the approach from the signal location.

The traffic signal installation at the intersection conformed to the national standards (4). During the research periods, the signal indications followed a simple 2-phase pattern with no all-red intervals. During other periods, the signals were placed on flashing operation.

A 20-pen operation recorder was employed to make a master record of signal indications, vehicle detections, timing pulses, and identification codes. Figure 2 shows the chart record produced during a demonstration run. The identification of each chart marking has been added to the illustrated record. The accuracy of the chart record and supplementary chart-processing equipment was evaluated; the measured trap times were found to be accurate to within $\frac{1}{20}$ sec 95 percent of the time. The speed of a vehicle traveling 50 mph was measured, using this system, to an accuracy within ±0.8 mph 95 percent of the time.

The 3 displays employed in this study were incorporated into a small box, as shown in Figure 3, that was positioned on top of the dashboard of the test vehicle. When the auditory display was activated, a miniature loudspeaker connected to a tape deck containing a prerecorded message warned of the traffic signal ahead. Following this message, an audible "beep" tone informed the driver when he would encounter a red or yellow signal. The tone was not heard if the signal to be encountered was green.

The light display illuminated 1 of 3 colored lights on the display panel—red, yellow, or green—to indicate the signal the driver would encounter on reaching the signal installation if he continued at his present speed.

The colored-band display depicted one complete cycle of traffic signal indications. A movable pointer above the colored band indicated the color to be encountered and also indicated the point in time during the cycle that the driver was destined to arrive at the signal.

All 3 displays were personal; that is, the information transmitted to the driver was related specifically to the approach of his vehicle relative to the signal timing. The information indicated what the signal status would be on his projected arrival at the signal. The projected arrival time was based on the driver's current speed. All 3 displays were also dynamic; that is, the information displayed was continually updated to reflect the effect of changes in speed on the signal indication that would exist when the vehicle reached the signal. All 3 displays were activated before the signal became visible to the driver.

For this research study, prototype hardware to perform the control and computational functions was not developed. Instead, these functions were simulated by the use of a manually operated electronic time-space diagram. The projected arrival time was transmitted to the test vehicle by a citizens band radio station operating between the control station and the test vehicle. A research assistant, riding in the rear seat of the vehicle to instruct the driver and answer questions, received instructions through an earphone and, unknown to the driver, manually adjusted the switches and dials on the display control panel as required to effect the appropriate display.

Six specific projected arrival times were selected as test conditions for this study. The timing of the signal controller was synchronized with the approach of the test vehicle such that the vehicle would normally approach the signal following one of the 6 time-space relations shown in Figure 4. This synchronization was accomplished by braking the cycle unit drum of the signal controller at the appropriate advance setting. As the test vehicle passed a synchronization detector at a prearranged speed, the brake would be released automatically, thereby establishing the desired relation.

Thirty individuals, representing a heterogeneous mix of driving experience and vehicles, were selected to serve as test drivers. The equipment was installed in each test driver's personal car, and the driver was instructed in the experimental procedure. He then made several practice runs to become familiar with each of the displays and with their responsiveness. The driver then made 24 test runs in order to subjectively evaluate the displays. During each test run, the driver attempted to drive as safely and smoothly as possible. Each combination of signal approach condition and display condition was presented to each test driver in a randomized sequence that was different for each driver.

At the conclusion of the test runs, each driver received a questionnaire in which he reported his opinions, observations, preferences, and comments regarding the operation and components of the 3 displays. The questionnaire was actually a ruse, for the evaluation of the 3 displays was based on the operation recorder record of each test run obtained with the buried detector loops. For this reason, the results of the questionnaire are not included here (3). Drivers were cooperative and seemed to believe the experiment was subjective rather than objective in nature.

ANALYSIS

The markings recorded on the operation recorder charts were converted to coordinates and punched into data processing cards for subsequent computer processing. A Benson-Lehner model Oscar F film-chart reader and digital converter were used in processing the operation recorder records. In using this equipment, one merely positioned a movable cross hair directly over each desired marking on the chart and pressed a button. The equipment then determined the numerical coordinate of that point and caused the coordinate to be punched into a data processing card. Only 4 of the 720 test runs had to be discarded because of malfunctions in the recording or study equipment. For each run, a tabulation similar to that shown in Figure 5 was prepared by the computer.

Thirteen travel characteristics were determined for each test run as follows:

1. Trap speeds, the effective spacing between successive detector loops (spaced 150 ft apart) divided by the measured time to traverse the respective traps;
2. Maximum speed, the maximum of the 13 trap speeds;
3. Speed range, the maximum of the 13 trap speeds less the minimum of the 13 trap speeds;
4. Intersection speed, the trap speed measured immediately in advance of the intersection;
5. System travel time, the total time required to travel the 1,950 ft between the first and the last detector loops;
6. Sum of speed changes, the sum of the absolute difference in speed between each successive pair of traps;
7. Number of speed reversals, the number of changes in speed from accelerating to decelerating and vice versa—provided, however, that the magnitude of the speed change exceeded the magnitude of the error inherent in the speed-measurement system;
8. Maximum deceleration rate, the greatest speed reduction between any 2 successive traps;
9. Intersection deceleration, the speed reduction during the 300 ft immediately prior to entering the intersection;
10. Intersection delay, the time to traverse the trap located immediately in advance of the intersection less the time to traverse the trap 450 ft farther upstream from the intersection;
11. Position at beginning of yellow, the distance from the intersection to the front bumper of the approaching vehicle at the instant the yellow signal indication began;
12. Position at beginning of red; and
13. Position at beginning of green.

The measures related to the safety of the run include maximum speed, intersection speed, system travel time (overall speed), maximum deceleration rate, intersection deceleration, and position of the vehicle at the beginning of the yellow, red, and green signal indications. The measures related to the smoothness of the run include number of speed reversals, sum of speed changes, speed range, maximum deceleration rate, intersection speed, and intersection delay.

Although each of these 13 travel characteristics was determined for each run, only those of significance to a particular signal approach condition were included in the analysis for that signal approach condition. For example, intersection speed, system travel time, and position at beginning of green would be unimportant to those runs that required the vehicles to stop and wait for a red signal indication.

RESULTS

Before the results of the various test runs were compared, validation checks were made on the data. These checks established that the initial speeds for all 24 test conditions (6 signal approach conditions and 4 display conditions) were not significantly different. They also established that the travel characteristics of the test drivers when they had no displays were essentially the same as the travel characteristics of drivers in the existing traffic at the study site.

Analysis of variance was used to make comparisons separately for each of the 6 signal approach conditions. Each appropriate travel characteristic and trap speed was compared across the 4 display conditions. Statistically significant differences were noted. The in-vehicle display associated with the safest or smoothest travel was identified, and the travel characteristic using that display was compared with the travel characteristic using no display.

Table 1 gives the results of the travel characteristic summaries and t-tests of the best and no-display conditions. A plus sign in the last column of this table indicates the best display value was smoother or safer than the no-display value. A negative sign indicates the opposite.

The average speed profiles for signal approach condition F are shown in Figure 6. The average speed profiles for the 3 displays appear to be similar. The light display appears to have resulted in an earlier response to the displayed information than the other 2 displays, judging by the speed profile characteristics for the first 3 traps. The no-display speed profile is significantly different from the other display conditions except for traps 1, 8, 9, and 10. The speed variances, based on Bartlett's test for homogeneity of variance, were not significantly different from trap to trap.

Similar analyses of the speed profiles were undertaken for each of the other signal approach conditions, but space does not permit a detailed presentation here (3).

Of the 51 travel characteristic measures compared and given in Table 1, 24, or almost 50 percent, yielded significant differences between the best display and the no display. Of those 24 significant differences, 21, or 88 percent, had safer or smoother travel with an in-vehicle display than without one.

Of the 21 significant differences yielding smoother or safer travel with an in-vehicle display, the light display ranked best 17 times, the auditory display ranked best 2 times, and the colored-band display ranked best 2 times. Also, 16 of these differences, or 76 percent, were associated with signal approach conditions requiring traffic to slow or stop for a red signal indication.

DISCUSSION OF RESULTS

The primary objective of this research was to determine whether a personal, dynamic, in-vehicle display could aid automobile drivers in making a smoother and safer approach to a traffic signal. This research definitely shows that such a display did enable many drivers to make a smoother and safer approach to the traffic signal.

However, the provision of such a display did not make every run smoother and safer. Some drivers elected to ignore the displayed information during certain signal approach conditions, and they drove their cars as though they had no display. Other drivers were sometimes confused, were uncertain as to how they should respond, or exercised poor judgment. As a consequence, their approach to the traffic signal was neither smoother nor safer than their approach without a display. In some individual cases, the approach was considerably more hazardous and erratic with the colored-band display than with no display.

A subsequent conversation was held with one of the few test drivers who consistently seemed to have ignored the displayed information when the projected signal indication was red. He indicated in this conversation that he personally felt more comfortable approaching the red signal indication at his normal approach speed, even though he knew he was going to be stopped, rather than slowing down earlier and "creeping" up to the intersection at what he considered to be an unnatural speed.

When all test runs with a display versus all test runs without a display are considered, the improvement in smoothness and safety as a result of drivers' having a display was not significant. However, when test runs with only the best of the 3 displays were compared with test runs without a display, there was a very marked improvement in smoothness and safety, as indicated by the results given in Table 1.

A possible cause for the high variations observed in the trap speeds for the colored-band display stems from the information presented by the display. Drivers were informed by this display of their exact arrival point during the signal cycle. This information gave the driver assurance that he could speed up, slow down, or alter his speed and know that in so doing he would still arrive at the signal during the green signal indication. With the auditory and light displays, the driver was informed that, if he maintained his then current speed, he would arrive at the signalized intersection as indicated by the display. Consequently, with the auditory and light displays, the drivers

Figure 1. View of test approach from signalized intersection.

Figure 2. Operation recorder chart produced during demonstration run.

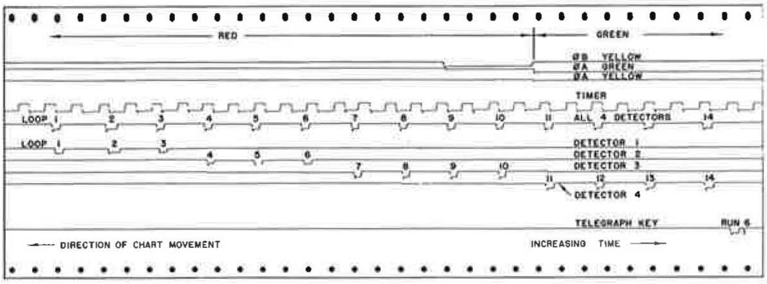

Figure 3. Display panel positioned on top of dashboard of test vehicles.

Figure 4. Time-space diagram of approach conditions studied.

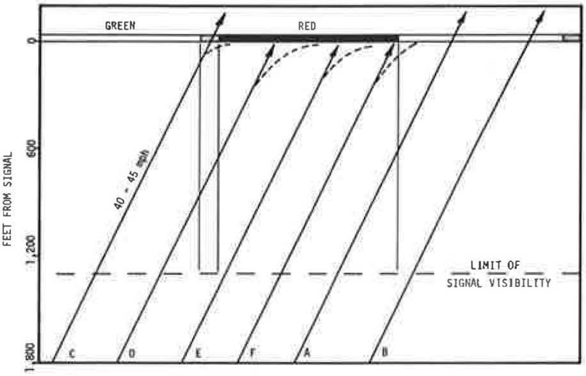

Figure 5. Analysis of operation recorder chart.

```
RESULTS OF TEST RUN 02-06-2A

TIME BASE =  184.43 UNITS
DEVIATION =    1.48 UNITS
BASED ON 14. OBSERVATIONS

LOOP   FEET     PROJ      TRAP TRAP SPEED   SPEED
 NO     TO      TIME **   TIME SPEEDCHANGE  PROFILE
       SIGNAL  AT SIG     SECS  MPH   MPH

  1    1800
                          2.11 48.4               *
  2    1650    23.2 14                2.1
                          2.02 50.5                *
  3    1500    22.3 14                2.9
                          1.92 53.4                  *
  4    1350    21.2 14                1.1
                          1.87 54.4                   *
  5    1200    20.8 13               -2.5
                          1.97 51.9                  *
  6    1050    21.6 14               -1.2
                          2.01 50.8                 *
  7     900    21.8 14                2.4
                          1.92 53.1                  *
  8     750    21.3 14               -0.5
                          1.94 52.6                  *
  9     600    21.4 14               -0.9
                          1.97 51.7                  *
 10     450    21.6 14               -0.1
                          1.97 51.7                  *
 11     300    21.6 14                0.3
                          1.96 51.9                  *
 12     150    21.5 14               -1.2
                          2.01 50.8                 *
 13       0    21.6 14               -4.8
                          2.22 46.0             *
 14    -150

BEGINNING OF GREEN  340. FEET BEFORE SIGNAL;
                         BETWEEN LOOPS 10 AND 11;
                      SYNC TIME G =  17.1 SECONDS.

                    MAX.    MAX.    SUM     INT.    SPD.
RUN  NO. "    ID    SPD.    MIN.    CHGS    SPD.    CHGS
02-06-2A A    M2    54.4     8.4    19.8    50.8      4

MAX.    INTER    INTER    TVL.   LOCATION AT BEGIN
DECL    DELAY    DECEL    TIME   YELO    RED  GREEN
-4.8     0.0     -0.9     25.9    0.      0.   336.
```

Figure 6. Average speed profiles observed for signal approach condition F.

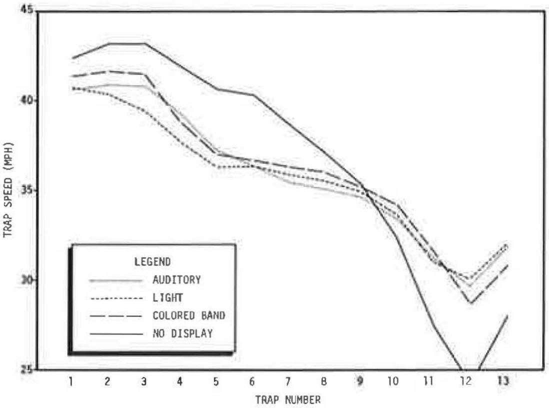

Table 1. Summary of results.

Travel Characteristic (avg)	Signal Approach Condition	Display				Best Versus None	Smoother or Safer[a]
		Auditory	Light	Colored Band	None		
Speed range	A	6.1	6.0[b]	6.5	7.8	0.01	+
	B	6.2	5.6[b]	6.5	6.9	0.01	+
	C (go)	8.5[b]	10.5	11.8	7.4	—[c]	
	F	14.8	13.7[b]	15.8	20.8	0.00	+
Sum of speed changes	A	12.8[b]	12.9	13.5	16.0	0.00	+
	B	13.5	13.0[b]	14.1	14.5	—[c]	
	C (go)	19.0[b]	20.6	22.0	15.7	—[c]	
	C (stop)	65.3	59.8[b]	69.6	56.6	—[c]	
	F	23.9	22.3[b]	23.5	28.8	0.00	+
Number of speed reversals	A	3.1[b]	3.2	3.1[b]	3.5	—[c]	
	B	3.2	3.2	2.8[b]	3.4	—[c]	
	C (go)	3.0	2.7[b]	2.7[b]	3.2	—[c]	
	C (stop)	4.1	3.6[b]	4.0	4.5	—[c]	
	F	3.8	3.4[b]	3.4[b]	2.9	0.01	-
Intersection delay	C (stop)	31.6[b]	31.8	34.0	34.4	—[c]	
	D	19.6	18.7[b]	19.9	22.3	0.01	+
	E	5.9	4.7[b]	5.9	8.0	0.00	+
	F	0.5[b]	0.5[b]	0.8	1.4	0.00	+
System travel time	A	32.1	32.1	32.5[b]	34.1	0.00	-
	B	31.3[b]	31.2	31.2	31.8	—[c]	
	C (go)	31.2[b]	30.7	30.0	31.5	—[c]	
	E	47.0	46.4[b]	46.8	47.5	0.01	+
	F	37.9[b]	38.0	37.9[b]	38.2	—[c]	
Maximum speed	A	44.3	44.2[b]	44.2[b]	43.0	—[c]	
	B	45.4	44.6[b]	45.7	45.0	—[c]	
	C (go)	46.4[b]	48.2	49.9	45.7	—[c]	
	C (stop)	42.8	42.5	42.4[b]	40.2	—[c]	
	D	43.7	43.4[b]	44.1	44.0	—[c]	
	E	43.8	43.3[b]	43.4	43.6	—[c]	
	F	42.6[b]	42.7	43.1	44.2	—[c]	
Maximum deceleration rate	C (stop)	25.7	24.1[b]	29.1	34.4	0.01	+
	D	20.3	19.8[b]	20.4	22.0	—[c]	
	E	12.2	11.1[b]	12.7	16.2	0.00	+
	F	5.2	4.7[b]	6.2	6.5	0.01	+
Intersection speed	A	40.2	40.1	40.0[b]	38.2	0.01	-
	B	41.4[b]	41.7	41.9	39.9	—[c]	
	C (go)	42.0[b]	43.3	43.9	40.4	—[c]	
	E	12.7	15.2[b]	13.7	9.6	0.00	+
	F	29.7	30.1[b]	28.7	24.4	0.00	+
Intersection deceleration	A	1.5	1.5	1.7[b]	0.3	0.03	+
	B	2.1[b]	1.9	1.9	2.2	—[c]	
	C (go)	2.5	3.4	3.6[b]	2.1	—[c]	
	C (stop)	30.7	29.0[b]	34.5	35.5	—[c]	
	D	25.6	24.6[b]	26.3	28.6	0.02	+
	E	16.6	13.6[b]	16.4	21.3	0.00	+
	F	3.7[b]	3.7[b]	5.5	8.0	0.01	+
Position at beginning of green	A	596	596	606[b]	662	—[c]	
	F	234	246[b]	229	188	0.02	+
Position at beginning of yellow	C (go)	43	9	-42[b]	57	0.01	+
	C (stop)	312	209	385[b]	212	—[c]	
	D	888	898[b]	861	863	0.00	+

[a] Plus means best display value was smoother or safer; minus means no display value was smoother or safer.

[b] Best display.

[c] Not significant.

seemed more likely to maintain their speeds when their arrivals would be during the green signal indication than to change their speeds and run the risk of changing their arrivals from the green signal indication to something less desirable.

A roadside traffic sign with a changeable message could be used to inform drivers in advance of a signalized location what signal indication to expect when they arrived at the signal. What then, one might ask, are the advantages of a personal, dynamic, in-vehicle display?

"Personal" means the information communicated to the driver is tailored specifically to fit his situation. The driver-aid information displayed in this study was based on the speed of that vehicle at that highway location at that instant in time. A roadside sign may be seen and read over a considerable length of roadway. At what point does the message apply to an approaching vehicle? If a driver observes a change in the message, which message should he believe? Unless the individual speeds of the approaching vehicles were detected and the appropriate message "flashed" to each driver, the sign message would likely be general in nature rather than personal.

"Dynamic" means the information is continually being updated as the driver responds to the message by a change in his speed. The displays employed in this project continually presented the latest up-to-date information about the signal indication until either the signal was reached or the vehicle approached a stop condition. The roadside sign would be located at one point and could, therefore, no longer communicate with the driver once it were passed. Furthermore, because it would be located at one specific point along the roadway, it would have no reference value. The driver could not refer back to it or recall the message if he were occupied with other driving tasks and not able to look at the sign at the instant it had to be seen.

"In-vehicle" means the information is presented to the driver by a display located inside the vehicle. An in-vehicle display would always be found in the same consistent position. The visibility of the display would not be affected by rain, snow, fog, darkness, shrubbery, dirt or moisture on the windshield, or other traffic blocking the view, as might occur with the roadside sign. Furthermore, the in-vehicle display would not be subjected to the hazards that roadside signs are subjected to, such as being knocked down or vandalized.

Where should the display be activated? To answer that question requires that a decision first be made pertaining to the objective to be served by the driver aid. One possible objective would be to inform drivers sufficiently in advance so that they can adjust their speeds in order to arrive at the signal during the green signal indication. This objective is comparable to the signal funnel concept. Another objective would be to give drivers sufficient advance warning of the signal indication to be encountered on their arrival at the intersection to enable them to respond in a safe and comfortable manner. The first objective attempts to alter the speeds of approaching vehicles; the second objective attempts to provide ample, advance warning.

This research has demonstrated that, although drivers did respond to advance information projecting a red traffic signal indication upon their arrivals, the magnitude of their speed changes was so slight that the display would have had to be activated several miles in advance of the signal to satisfy a signal funnel objective. Test drivers adjusted their speeds gradually and generally refused to proceed at speeds that seemed to be unnaturally slow.

The second objective, to provide sufficient advance warning to allow drivers to safely and comfortably respond, seems to be more realistic. At the study site for this project, many drivers did not respond to the need to stop until 500 or 600 ft in advance of the signal. Had the display been activated near this point, drivers would have had ample time (10 sec or more) to interpret the display and respond in a safe and comfortable manner.

This second objective also has value for adverse driving conditions, when fog or snow and ice on the roadway make travel hazardous. It would seem to be more valuable to a driver traveling under foul weather conditions to be informed 600 ft in advance of a signal that the signal will be red on his arrival than to be informed several miles from the signal how much to alter his speed so as to ensure his arriving on a green signal. In either case, the true total delay to the vehicle would be essentially the same. With the first objective, the delay would be spent on the approach. With the second objective, the delay would be spent waiting at the signal.

With an activation point relatively close to the signal, the dynamic character of this traffic-signal driver aid—updating the display to reflect the effect of changes in speed—would be relatively unimportant. Eliminating the dynamic aspect of this driver aid would greatly simplify the electronic components required to provide the driver aid. The in-vehicle and personal aspects of the display would still be extremely valuable in this case; but, without the dynamic features, these other aspects could more easily be accomplished at the roadside and the appropriate message for each individual vehicle could be transmitted to the vehicle for display by much simpler and less expensive electronic equipment.

In this research, the 3 displays were operated independently of one another in order to observe the effect that the component parts had on the test runs. The questionnaire completed by each test driver asked numerous questions about the component parts of each display. The responses varied. Some test drivers preferred the first, some the second, and others the third display. Some thought the beep tone should be louder; some thought the beep tone should be softer; some thought the beep tone was annoying and that provision should be made to turn it off. So it went with all the elements of the various displays. There were wide differences in opinions.

The one important message resulting from these varied responses is that some degree of flexibility in the design and adjustment of display components should be provided. Not all people are hard of hearing. Not all people would benefit by a "heads-up" type of display. Color-blind individuals might be aided by colored lights in a light display that were other than red and green. Individuals vary and their opinions vary. This variability should be recognized in designing an ideal display.

It seems that the simpler the display is, the more effective it will be. Presenting drivers with ready-made decisions to stop or proceed was better than giving them all the facts and expecting them to come up with the correct decision.

In keeping with this desirable, ready-made decision characteristic, and based on the results of this study and other research dealing with the design of displays, the ideal display for this application consists of a combination auditory-visual display presenting 2 possible messages: (a) prepare to stop and (b) proceed.

The visual part of the display would consist of 2 colored lights representing the stop and the go messages. Projected arrivals during the yellow clearance period should be split between the 2 possible messages in order to maintain the trust and confidence of drivers. The auditory part of the display would consist of an audible alert that would sound when the display was activated and a pulsing tone that would accompany the visual message to stop. The intensity of the lights as well as the loudness of the auditory signals should be adjustable for day versus night driving and for persons having different levels of auditory acuity.

CONCLUSIONS

The following conclusions were reached as a result of this study.

1. A personal, dynamic, in-vehicle display was able to aid drivers in making a smoother, safer approach to the traffic signal installation at the test site, especially when a red signal indication was to be encountered.
2. The light display was the display most effectively utilized by the test drivers, the auditory display ranked in second place, and the colored-band display was last.
3. Driver response to information that a red signal indication would be encountered resulted in lower approach speeds. Although statistically significant, the magnitude of this speed reduction was not large. Drivers adjusted their speeds gradually and generally refused to travel at speeds that seemed to be unnaturally slow.
4. This driver-aid concept was felt to be worthy of further research and development. The in-vehicle display configuration recommended for a continuing phase of this project consists of a combination auditory and light display having a personal, binary message. It is recommended that the display be activated to warn and inform drivers rather than to attempt to funnel them into the green intervals.

ACKNOWLEDGMENTS

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RECOGNITION OF TRAFFIC-CONTROL SIGNS

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The paper includes a review of published and unpublished literature with respect to symbols versus word messages on traffic signs, symbolization philosophies and recognition problems, and education of motorists about meanings of symbols. The paper also reports on a laboratory study and a field study of traffic-sign recognition. The laboratory experiment was conducted to determine the ability of subjects to recognize selected turn-restriction signs under conditions of short exposure. The traffic signs were varied by types of turn restrictions and mode of indicating the sign message, i.e., words, positive and negative symbols, and combinations of these. The experiment made use of a projection tachistoscope. Subjects varied in age, driving skill, and experience. The field study compared the effectiveness of both negative and positive symbols. The effectiveness was measured in relation to the number of motorists disregarding the turn-restriction sign.

•DURING the past 2 decades there has been a considerable emphasis on the need to standardize, on an international basis, the use of traffic-control signs. The issue is particularly important because large numbers of people drive in foreign countries and are unfamiliar with verbal legends in different languages. Earlier attempts were made to establish an international standard of signing, but the first major one was the United Nations 1949 Protocol on Road Signs and Signals. A good deal of work has been done on traffic-sign recognition and the requirements for adequate traffic signs (3). However, there has been relatively little research to evaluate the relative effectiveness of different ways of conveying the same information to motorists.

SYMBOLS VERSUS WORD MESSAGES

In an early investigation of highway signs, Janda and Volk (5) used a reaction time measure to demonstrate that an arrow alone was the best indicator of directional control, words and arrows combined were the second best, and words alone were the worst. Elliot (2), in a discussion of the use of symbolic traffic signs at the international level, indicates that very few symbols communicate their meaning well without other associated symbols such as inscriptions or markings. The use of a symbol assumes that the viewer knows the meaning of it. It is generally assumed that certain symbols or pictures will be understood on the basis of some intrinsic meaning that is obvious to all; however, cultural differences do exist, and some symbols may be inappropriate for certain countries. By 1960, a large number of European and near-eastern countries were using the United Nations 1949 Protocol. However, North and South America tended to use the United States standard, which differed from the United Nations system.

Gray and Russell (4) conducted a study in which they examined the recognizability of symbolic road signs used in parts of Europe. Twelve mandatory and warning signs that carried no words were examined. Easily interpreted signs such as STEEP HILL were understood by more than 90 percent of the drivers. However, signs with more abstract

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*This research was conducted while Mr. Dewar was with the University of Calgary.

symbols were recognized by as few as 50 percent. They concluded that signs that relied on purely abstract symbolism were difficult to understand.

Markowitz et al. (7), in a laboratory study of traffic-sign recognition, examined 2 versions of 5 separate traffic signs. These were YIELD, DO NOT ENTER, NO RIGHT TURN, SCHOOL CROSSING, and STOP. Although the signs without written messages appeared to be slightly more recognizable, when individual signs having the same meaning were compared with each other (e.g., 2 different NO RIGHT TURN signs), those composed of a written message were slightly easier to recognize than those depicted with a symbol.

Walker, Nicolay, and Stearns (9) investigated the hypothesis that symbol road signs are more easily recognized than verbal signs. The signs tested were NO RIGHT TURN, NO LEFT TURN, DO NOT ENTER, and their symbol counterparts (similar to the international signs used in Europe). They were presented with a tachistoscope for 0.06 sec to small groups of subjects. Correct recognition occurred for approximately 84 percent of the symbols and 55 percent of the written messages.

Using motion picture film, Tierney and King (8) examined glance legibility for written messages and for symbols from the Canadian-Pan American system and from the Quebec-United Nations system. The 2 groups of symbols were more readily recognized than were the words. Subjects were asked the meanings of the symbols before the recognition test. Errors in identification were 52.5 percent for the Quebec-United Nations symbols (all of which were prohibition signs) and 27.3 percent for the Canadian-Pan American symbols (all of which were regulatory or warning signs). The former series of symbols had a high proportion of "opposite" interpretations. Unfortunately, this study did not use different versions of signs having the same meaning, so a direct comparison of symbol systems was not possible.

Until recently, the United States system differed from many others in that it tended to use written messages rather than symbols. A symbol may be visible at a greater distance than the written message on a sign of equal size. The length of different messages requires different sign shapes and sizes and varying letter types and sizes to accommodate those messages; therefore, uniformity is impossible, particularly in signs that are meant to be regulatory. The symbol does not pose these problems. Not all messages can be represented in a symbol. For example, how would one symbolize KEEP RIGHT EXCEPT TO PASS or SLOW DOWN? It seems reasonable to conclude that to date the evidence comparing symbols and word messages in traffic control signs is inconclusive and insufficient.

SYMBOLIZATION PHILOSOPHIES AND RECOGNITION PROBLEMS

There are contradictory philosophies reflected in the current use of symbols. For example, they may reflect the nature of a hazard, such as a bump in the road, or the result of a hazard, such as a skidding car on a slippery road. Another example of inconsistency is the positive versus negative instructions (a problem of stimulus-response compatibility). The need for visual consistency is overlooked here. The basic problem is whether these signs should indicate to a driver what he must do or tell him what he must not do. Research on the relative merits of these 2 approaches is difficult to find. Frequently, in determining recognizability of traffic control signs, researchers are concerned with simply whether the sign is recognized or can be named. Perhaps it would be better to be more concerned about determining what action the driver would take in response to a sign and less concerned about producing a textbook definition.

A study by Kershaw (6), conducted in 1968 at the Central Canada Exhibition in Ottawa, employed a questionnaire with 10 items in which subjects were asked the meaning of a variety of traffic symbols. The ones of primary relevance here were 2 versions of the DO NOT ENTER sign. More than 2,500 subjects completed the questionnaire. Two symbolic versions of the DO NOT ENTER sign were used—a white horizontal bar on a red circle (the European interdiction symbol) and an arrow pointing straight ahead with a red slash through it and a red square around it. The former sign was correctly interpreted by approximately one-third of the respondents, and the latter sign was responded to correctly by two-thirds of the respondents. However, 18 percent of respondents indicated that the latter symbol meant to proceed straight ahead (a serious error).

A study conducted in Winnipeg (1) examined several traffic-control signs. The positive NO LEFT TURN symbol was identified correctly by 77 percent of the subjects (recognition dropped to 66 percent when the sign included a time restriction). Correct identification of 3 versions of the DO NOT ENTER sign varied from 56 to 87 percent, but when a time restriction was added performance was reduced from 20 to 38 percent. For some reason the time restrictions seemed to interfere with correction recognition.

The desirability of having a worldwide system of traffic-control signs is evident. Although some research has been done to determine what symbols are most adequate for communicating information to drivers, a good deal more is needed. The first study reported here was intended to meet this need in a small way by comparing the recognizability of different versions of 4 traffic-control signs used in Canada.

LABORATORY STUDY OF TRAFFIC-SIGN RECOGNITION

Method

An experiment was conducted to determine ability to recognize selected traffic-control signs under conditions of short exposure. The experiment was carried out in 2 parts. Part 1 involved recognition of full colored slides of traffic signs flashed on a screen by a LaFayette model T-2K projection tachistoscope for a duration of $\frac{1}{25}$ sec. An interval of 10 sec elapsed between slides. So that no signs would be unfamiliar to them, subjects were shown slides of all signs for 30 sec each and told the meaning of each before the experiment began. Subjects were required to identify each sign and write their answers in the appropriate places on an answer sheet provided. Additional information gathered included age and sex. Twenty-three signs were presented in part 1. Table 1 gives a description of the sign messages; Figure 1 shows examples.

Part 2 involved recognition of the same signs in a photograph taken of an intersection at a distance of 100 ft from the near side of the intersection. The traffic signs were hung above the far side of the intersection, a distance of 232 ft from where the photograph was taken. Slides of this scene were presented to subjects for $\frac{1}{5}$ sec. Two additional NO TURN signs were presented in part 2—positive symbol with words and words with time. The order in which slides were presented was randomized within each part of the experiment. There was a rest period of 2 min between parts 1 and 2. Part 1 was administered first in all cases, and the procedure was identical for both parts.

Samples

Three samples of subjects were used. The first involved a group of 148 volunteers who were employees of the city of Calgary. They ranged in age from 18 to 63 years. Those subjects, tested in groups of 6, were seated at tables in a semicircle 18 ft from the screen on which the slides were projected. The projector was located 24 ft from the screen.

The second sample involved driver trainees who were taking a 4-week (40-hour) driving course through the Alberta Motor Association. Students were tested both before and after the driver training course (on the first and last days). One hundred and thirty-three subjects were tested in the before phase, and 83 in the after phase. These subjects were much younger than those in the preceding sample; most of them were between 15 and 22 years of age. One additional driver-training class, 57 students, was tested after training was completed to assess the possible practice effect that might be operating in the samples tested both before and after driver training. The driver-trainee samples were divided into groups ranging in size from 42 to 68 and tested in a classroom 40 ft in length where the projector was 36 ft from the screen. The distances from the screen ranged from 15 to 40 ft for different subjects, who were required to indicate on their answer sheets the row in which they were sitting. Subsequent analyses indicated no differences in accuracy of recognition of the traffic signs on the basis of distance from the screen. Therefore, the data of all the subjects were pooled for the purpose of statistical analysis.

Results

The percentage of correct responses to each of the different types of traffic-control signs is given in Table 2 for all of the samples. A composite score for the 4 versions of the left- or right-turn restriction signs comprised the total correct out of the 4 responses—combining NO LEFT TURN and NO RIGHT TURN (e.g., there were 4 turn-restriction signs in the form of the negative symbol; a subject recognizing 3 of these correctly received a score of 3 for that sign).

Selected comparisons were made by the use of the t-tests. Table 3 gives the signs that were compared and the t-values and the levels of significance. This analysis was conducted for the city employee sample as well as the driver trainees tested before and after training and trainees tested after training only. There were no systematic differences across the different samples for the signs presented in part 1 of the experiment. However, the driver trainees before training did consistently better in part 1 on traffic signs that contained symbols than on those that contained words only. Consistent trends in part 2 indicate 3 comparisons to be statistically significant for all 3 samples: the positive turn-restriction symbol was more easily recognized than either the negative symbol or words alone; the positive turn-restriction symbol with words was more easily recognized than words alone. The only sign in which words alone were better recognized than the symbol was the NO U-TURN sign. In general, where a sign was compared with a similar sign containing additional information, such as time or words or both, the simpler version was more easily recognized. Adding something to a sign appears to increase confusion and make the symbol more difficult to recognize.

A series of chi-square analyses conducted on the city employee sample compared the subject's performance in recognizing each of the traffic signs with age and sex. There were no systematic sex differences in this sample of 116 males and 32 females, with the exception that males performed better on the negative turn-restriction symbol, RN2, ($X^2 = 11.47$, df = 4, and $p < 0.025$).

A few age differences did emerge. All differences favored younger subjects, who performed better on the following signs:

Sign Code	X^2	df	p
RN1	15.70	6	0.02
RW2	15.19	6	0.02
TPt1	9.67	3	0.05
UNW2	9.68	3	0.05

(Degrees of freedom are not the same for all signs because data had to be collapsed in instances where there were too few cases per cell.) Older subjects generally had more difficulty with words alone than with symbols.

A comparison of the performance of driver trainees tested both before and after training and trainees tested only after training (to eliminate practice effect) indicated that the training had a possible enhancing effect on the recognition of only 3 signs. Substantial improvement after training occurred on sign TW2, and slight improvement occurred on signs TW1 and UNW2.

Because of the large number of comparisons made, one would expect a certain number of significant results by chance. Therefore, any differences statistically significant at < 0.025 were not considered reliable differences.

FIELD TEST OF NO-LEFT-TURN SYMBOLS

Additional information concerning the relative effectiveness of the negative and positive symbols for NO LEFT TURN was gathered in a study that was carried out at an intersection in the city of Calgary during a period of 2 years. The particular intersection involved a main north-south street that carries traffic between downtown and residential areas and a main east-west street (4-lane, undivided) that is also part of the Trans-Canada Highway. Left turns off the east-west street were prohibited between 4 and 6 p.m. Before May 1969, this had been indicated by a positive symbol for NO LEFT TURN with the written message NO LEFT TURN 4-6 PM. On Monday, May 6, 1969, this sign was replaced by a negative symbol with the same words and time.

Method

The relative effectiveness of these 2 symbols was measured by counts of the number of vehicles that made illegal left turns during the specified 4 to 6 p. m. period. The count was first taken during the week before the sign was changed (April 28 to May 4, 1969). The immediate impact of the new sign was measured by the number of violations immediately following its installation (May 6 to 18). A follow-up was conducted 6 weeks later (June 16 to 22) after motorists had become accustomed to this new sign (very few were in use in the city at the time). The measure was repeated in the spring (April 20 to 26 and June 15 to 21) of the following year after any novelty effect or unfamiliarity with the meaning of the new sign had dissipated. An additional follow-up 2 years later (April 26 to May 2, 1971) was also conducted to further determine the long-term effects.

An index of the daily traffic volume was determined by counts of the number of vehicles that traveled eastbound and westbound during 16 specified green-light periods during the 2-hour interval. From 4 to 6 p. m., traffic volume in each direction was counted once every $7\frac{1}{2}$ min.

Results

In the analysis, account was taken of the volume of traffic as well as of the number of violations. A daily "violation index" was calculated as follows:

$$\text{Violation index} = \frac{\text{violations}}{\text{average number of vehicles per green light}}$$

The main findings for eastbound and westbound vehicles are given in Table 4. These data and all statistical tests are based on violations during weekdays only. Frequency of violation and the violation indexes increased by a factor of 3 to 7 on weekends. This was probably due to motorists' assumption that the restriction did not apply on weekends. The violations for westbound vehicles were consistently higher that those for eastbound vehicles, even though the volume of traffic was approximately equal in both directions. This difference is likely due to the large number of out-of-town vehicles turning left to travel southbound to the city center. During April and June 1970, the daily average number of violations by out-of-town drivers was 7.5 for westbound vehicles and 1.1 for eastbound vehicles.

In addition to the mean daily violations and the violation index, Table 4 also gives a second mean daily violation count and violation index. These second measures were calculated because of the large number of violations that occurred just after 4 p. m. and just before 6 p. m., at which time drivers were possibly unaware of the exact time or were more likely to commit violations because the traffic is lighter. The second measures omitted the 15 min after 4 p. m. and the 15 min before 6 p. m. The results show a somewhat smaller daily mean and a considerably smaller violation index when they are based on these restricted data. Violations decreased and traffic volume increased during this time.

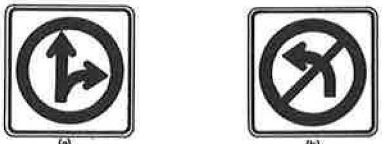
The results indicate no systematic change in the number of violations for eastbound traffic. Westbound traffic, however, showed a somewhat higher violation index for

Table 1. Messages on signs showed to subjects.

Part	Sign Type	Sign Message		Sign Code
		Symbol	Other	
1	No left turn	Positive		LP1
		Negative		LN1
			Words	LW1
		Positive	Words	LPW1
	No right turn	Positive		RP1
		Negative		RN1
			Words	RW1
		Positive	Words	RPW1
	No turns	Positive		TP1
		Positive	Time	TPt1
		Positive	Words and time	TWWt1
			Words	TW1
	No U-turn		Words	UW1
		Negative		UN1
		Negative	Words	UNW1
2	No left turn	Positive		LP2
		Negative		LN2
			Words	LW2
		Positive	Words	LPW2
	No right turn	Positive		RP2
		Negative		RN2
			Words	RW2
		Positive	Words	RPW2
	No turns	Positive		TP2
		Positive	Words	TPW2
		Positive	Words and time	TPWt2
		Positive	Time	TPt2
			Words	TW2
			Words and time	TWt2
	No U-turn		Words	UW2
		Negative		UN2
		Negative	Words	UNW2

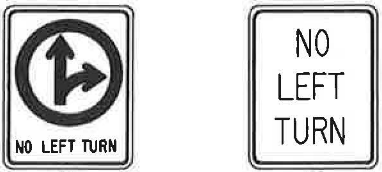
Note: Left- and right-turn signs were presented twice.

Figure 1. Examples of traffic signs used in experiment.



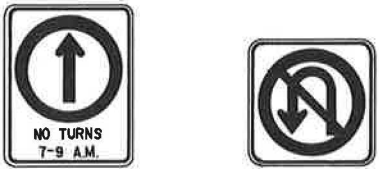
(a)
CIRCLE GREEN
ARROW AND BORDER BLACK
BACKGROUND WHITE

(b)
CIRCLE AND BAR RED
ARROW AND BORDER BLACK
BACKGROUND WHITE



(c)
CIRCLE GREEN
ARROW, BORDER, LETTERS BLACK
BACKGROUND WHITE

(d)
LETTERS, BORDER BLACK
BACKGROUND WHITE



(e)
CIRCLE GREEN
ARROW, BORDER, LETTERS BLACK
BACKGROUND WHITE

(f)
CIRCLE AND BAR RED
ARROW AND BORDER BLACK
BACKGROUND WHITE

Table 2. Percentage of subjects correctly recognizing traffic-control signs.

Sign Code	City Employees	Driver Trainees Before	Driver Trainees After	Driver Trainees After Only
RP1	77.7	69.6	83.7	48.7
RN1	77.9	73.7	82.5	67.1
RW1	78.1	62.9	69.0	59.7
RPW1	76.9	77.8	86.2	54.4
RP2	69.9	64.3	62.4	50.5
RN2	47.3	23.3	28.3	28.1
RW2	22.9	19.6	23.2	15.4
RPW2	63.7	42.1	59.3	45.2
TP1	89.2	88.0	91.6	75.4
TPt1	83.1	80.5	90.4	49.1
TPWt1	79.7	69.2	89.2	63.2
TW1	35.8	21.8	36.1	29.8
TP2	73.7	33.8	50.6	36.8
TPW2	62.2	37.6	42.7	38.6
TPWt2	72.9	41.4	50.6	26.3
TPt2	64.8	50.0	54.1	33.3
TW2	61.5	27.8	53.0	49.1
TWt2	37.8	27.1	36.1	38.6
UW1	91.2	92.5	97.6	91.2
UN1	90.5	85.7	90.4	75.4
UNW1	91.2	63.9	90.4	68.4
UW2	64.9	19.6	27.7	26.3
UN2	52.7	17.3	22.9	15.8
UNW2	46.0	18.8	31.3	29.8

Table 3. t-test comparisons of traffic-control signs.

Codes of Signs Compared	City Employees	Driver Trainees Before	Driver Trainees After Only
RN1 and RP1	0.048	1.127	2.970[a]
RP1 and RW1	-0.107	12.961[a]	-1.852
RN1 and RW1	-0.057	14.623[a]	1.391
RPW1 and RW1	-0.384	15.357[a]	-0.836
RP2 and RN2	5.325[a]	6.174[a]	4.133[a]
RP2 and RW2	12.749[a]	7.828[a]	7.105[a]
RN2 and RW2	6.661[a]	1.248	2.857[a]
RPW2 and RW2	11.284[a]	7.090[a]	5.680[a]
TP1 and TPWt1	2.260[b]	3.805[a]	1.399
TP1 and TPt1	1.514	1.673	2.757[a]
TPt1 and TPWt1	0.748	2.124[c]	-1.313
TP2 and TPW2	2.102[c]	-0.642	-0.195
UW1 and UN1	0.208	1.776	2.537[a]
UW2 and UN2	2.134[c]	0. 460	1.363

Note: Positive values indicate that the first of each pair of signs was more easily recognized.

[a] $p < 0.01$.
[b] $p < 0.02$.
[c] $p < 0.05$.

Table 4. Main daily violations and violation indexes.

Date	Eastbound				Westbound[a]			
	Violations 1	Index 1	Violations 2[b]	Index 2[b]	Violations 1	Index 1	Violations 2[b]	Index 2[b]
April 28-May 2, 1969	8.8	0.60	4.8	0.18	12.4	0.81	5.6	0.20
May 6-9, 12-16, 1969	8.8	0.48	4.1	0.15	12.7	0.79	7.3	0.25
June 16-20, 1969	9.4	0.74	4.0	0.18	29.8	2.11	15.2	0.58
April 20-24, 1970	9.4	0.48	5.0	0.14	23.0	1.21	14.0	0.40
June 15-19, 1970	10.2	0.45	4.8	0.15	26.4	1.10	15.2	0.44
April 26-30, 1971	13.2	0.72	7.4	0.20	**	**	**	**

[a] Data for westbound traffic in April 1971 were not obtained because the turn restriction had been removed at that time to allow a temporary rerouting of traffic entering the city from the north.
[b] Based on violations committed between 4:15 and 5:45 p.m.

both total and restricted data after May 1969. There is no evidence to suggest that the negative-symbol version of the NO LEFT TURN sign improved traffic control for the purpose for which it was intended. The only statistically significant differences were (for violation index 2) between April 1969 and June 1969, when there were more westbound violations in June ($t = 2.99$, $df = 8$, $p < 0.05$), and between April 1969 and April 1970, when there were more westbound violations in April 1970 ($t = 2.56$, $df = 8$, $p < 0.05$). This first difference may be attributable partly to the large number of westbound out-of-town cars committing violations (an average of 9.3 per day during the June 1970 period).

CONCLUSIONS

The purpose of these investigations was to examine the recognizability and effectiveness of selected traffic-control signs. The laboratory approach, in which the projection tachistoscope is used, is a good method for studying traffic-sign recognition under controlled conditions. However, there are limitations here in that the subject is not exposed to the many distractions that he encounters while driving. In addition, the primary concern in traffic control is not whether the driver recognizes a sign but whether he obeys it. The field study was an attempt to examine this aspect of the problem.

There is evidence from both studies to suggest that the positive symbol was better than the negative symbol for the turn-restriction signs. This may be due to the positive sign being more intrinsically meaningful, or possibly to the fact that they have been in more common use in Alberta and are simply more familiar. Word messages were generally more poorly recognized than symbols.

Comprehension of a symbol is reduced by the addition of information such as words or a time. In such cases, the subject is required to process more information and will often miss part of it.

Evidence from the field study is not conclusive. The increase in violations for westbound traffic 6 weeks after the negative sign had been installed may be due to factors such as weather conditions and type of drivers. The most meaningful comparison is that between violations of the original sign and violations of the new sign during the same time of the year 1 year later (April 1970). In this comparison, the westbound traffic between 4:15 and 5:45 committed more violations in April 1970—tentative evidence that the negative turn-restriction symbol was less effective than the positive symbol under these particular circumstances. Ideally, data should have been collected during May and June before the negative symbol was installed so that more meaningful comparisions could be made. Another desirable modification would be to repeat the field study at a location where drivers are unfamiliar with both the positive and negative symbols.

A number of suggestions for future research emerge from this and other studies on traffic signing. Of particular interest from a psychological point of view is the problem of stimulus-response compatibility. Should the message indicate what the driver can do, or what he cannot do? The present research hints that the former may be desirable. Basic research on the use of unfamiliar symbols (not traffic signs) is warranted to determine the information processing requirements of the task.

The dozens of symbols used in traffic control need to be examined for their recognizability. Comparisons of different ways of presenting the same message should be made. This is especially important with abstract symbols that have no intrinsically obvious meaning to most motorists. Such research must, of course, be done cross-culturally if an adequate set of symbols is to be developed for international use.

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CRITERIA FOR DESIGN AND DEPLOYMENT OF ADVANCED GRAPHIC GUIDE SIGNS

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This study was designed to determine the graphic sign characteristics that best communicated roadway-interchange and route-guidance information to the driver. Emphasis was placed on (a) developing laboratory sign-testing procedures for determining the effectiveness of signing alternatives and (b) developing analytical techniques for identifying interchange characteristics where graphic guide signs might be required and applicable. In the laboratory sign-testing procedure, one 35-mm slide projector showed a roadway scene in which the guide signs were blacked out and another projector showed a scale-model test sign in the blacked-out area for 1 sec. Characteristics of interchanges where graphic guide signs should be considered were identified by theoretical analyses. Laboratory tests indicated that route-guidance was provided significantly better by graphic signs than by conventional signs on certain interchanges. Graphic signs also convey relative exit speeds and lane-drop information effectively.

•THE IMPETUS for this study came largely from 2 sources. One was the contention that present guide signs are not doing all that they might to facilitate traffic flow and reduce accidents; the other was the experience of many people with the symbol and diagrammatic signing prevalent in Europe (1). These led to the belief that better signs are possible and that better signs may be diagrammatic.

Accordingly, the Office of Traffic Operations of the Federal Highway Administration initiated a series of demonstration projects (2, 3, 4) on diagrammatic guide signs. Each of these projects incorporated an evaluation program of the sign or signs that were erected under the project. Although several of the projects yielded significant results, the projects together were inconclusive. Perusal of the diagrammatics employed indicates that several conceptions of "diagrammatic" were employed and that this may be the reason for the inconclusiveness.

The study presented here was initiated by the Driver Performance Research Division of the National Highway Safety Bureau (now the National Highway Traffic Safety Administration) to address the questions raised by previous research. Specifically, the purpose of the study was to develop a laboratory test procedure, develop diagrammatic guide signs, analyze the effect of interchange characteristics, and use the laboratory procedure to test the signs and interchange characteristics.

APPROACH AND FINDINGS

This study was undertaken to develop a laboratory sign-testing method and to apply this method to specify the parameters associated with effective graphic or map signing. The functions performed are discussed below.

Sponsored by Committee on Motorist Information Systems.

Function 1: Identify Interchange Characteristics Potentially Requiring Graphic Guide Signs

Guidelines were prepared for specifying the particular locations where graphic guide signs might be more effective than conventional signs and for selecting the interchanges for laboratory testing. These guidelines were developed from a conceptual analysis of those interchange characteristics associated with traffic flow and accident-producing problems. Both the severity of the traffic flow problems and the potential impact of graphic guide signs were considered in the development of the guidelines.

Where 2 or more of the following characteristics occurred within a particular interchange, it was suggested that the effectiveness of graphic guide signs be tested: heavy ramp volume, perceptual problems (e.g., inability to see gore), difficult and dangerous last-minute lane changes, unexpected geometrics (e.g., inconsistent configuration), and interchanges where a wrong decision is difficult to rectify.

Two or more of the preceding characteristics are often associated with the following types of interchanges: collector-distributor with lane drop, multiple-lane split ramp (close choice points or gores), left ramp downstream from right ramp, multiple gore (2 choice points or gores in quick succession), major fork, and cloverleaf (heavy volume and sight distance problems). Therefore, representative interchanges of each of the types given above were used in the study.

Function 2: Develop Sign-Effectiveness Criteria

Pilot studies were conducted to identify measures of guide-sign effectiveness. Only those measures that could be obtained in a laboratory setting were considered. The particular measures selected were as follows:

1. Lane choice (the selection of the most appropriate lane for a particular destination—right lane for right exits, left lane for left exits, and all but exit-only lanes for through destinations),
2. Confidence ratings (an indication of how confident subjects were in their lane choice—not at all confident, a little confident, somewhat confident, and very confident),
3. Interpretation of guide signs (a series of questions concerning the information conveyed by the guide sign including number of exits in the interchanges, number of lanes used for through traffic, location of exit of interest—first or second in the interchange, distance between exits, and estimated safe exit speed), and
4. Sign preference (selection of which sign configuration was preferred at different interchange types).

Function 3: Develop Laboratory-Testing Procedure

The primary concern of this phase was the development of reliable, sensitive, and efficient laboratory procedures for the evaluation of graphic and conventional guide signs. The subjects' task under each of the identified measures of guide-sign effectiveness was specified. The necessary methodology to measure the subjects' responses was devised. As an ancillary product of this function, alternative signing concepts were developed for later testing (modified conventional and performance constructed).

A dual-projection tachistoscopic method was developed and employed as the basic measuring technique. The procedure required the use of two 35-mm slide projectors. One projector presented slides of roadway scenes. The slides were taken from a vehicle positioned in one of the lanes on the road. An area of the roadway scene corresponding to the position of an actual road sign was blocked out. The second projector was equipped with a tachistoscopic shutter and projected slides of conventional and graphic signs. The graphic signs were projected into the blacked-out area of the background scene for 1 sec (a length of time derived from a series of pilot studies).

The double-projector tachistoscopic technique proved to be a sensitive method for measuring responses of subjects to signing variables both between and within interchanges. Because the method does not require expensive equipment (the purchase price for all of the equipment needed for the dual-projector tachistoscopic method was under $1,000), has high reliability, and is portable and simple to operate, it is particularly appealing as a research tool. The sign-testing procedure is feasible for testing proposed new sign configurations by highway departments.

Function 4: Test Guide Signs for Complex Interchanges

Guide signs were constructed for each of the test interchanges selected in function 3. The types of signs constructed for each of the interchanges are shown in Figure 1. Tests were administered at the Smithsonian Institution to visitors who volunteered to serve as subjects.

Technique 1: Proper Lane and Confidence Testing—The initial experiment was designed to determine which of the concepts shown in Figure 1 enabled the majority of drivers to get confidently into the proper lane. The 102 subjects were shown a roadway scene; test signs were projected onto a blank sign panel within the scene (Fig. 2). Subjects were told how to identify the proper lane and indicate their degree of confidence. Prior to each test, they were given a destination. After the presentation of a test sign, they indicated which lanes they should be in and their degree of confidence in their choices.

The results of the subjects' lane choices are given in Table 1. The findings do not clearly favor any one signing concept. The plan concept was significantly better than the other graphic sign concepts but not better than the modified conventional for the collector-distributor. The driver's eye was better than conventional for close choice points. There were no differences for the left exit or multigore areas. All graphic guide signs were better than the modified conventional at a major fork. At a cloverleaf, the modified conventional was significantly better than the driver's eye or plan. Confidence ratings were not helpful in discriminating signs.

Because of the difficulties encountered with the conventional signs and because a series of signs are normally presented at an interchange, testing of conventional versus graphic guide signs was conducted. The same technique was employed. The results (Table 2) indicate significantly better performance when graphic guide signs are used for the collector-distributor ($p < 0.01$), close choice points ($p < 0.01$), and, to a less significant level, major fork ($p < 0.10$). The results generally are in agreement with the previous findings.

Technique 2: Preference Testing—A dual-projector technique was used to obtain driver preferences for guide signs at the various interchanges (Fig. 1). One projector presented a line-drawing map of the interchange, and another projected numbered sign concepts alongside the interchange (Fig. 3). The subjects selected the sign they "liked best" and "liked least" for each interchange. Subjects selecting the signs had previously performed under the lane-choice and confidence-testing technique.

Table 3 gives the preferred (liked-best) signs for each of the interchanges. Graphic guide signs received significantly higher preference ratings for all of the interchanges. The aerial or plan view received significantly higher preference ratings ($p < 0.05$) on all but the major fork, where the performance constructed was preferred (the performance constructed and the plan view were similar for the major fork). The conventional signs were least preferred.

Technique 3: Roadway Characteristics—The third technique was designed to determine whether graphic signs can convey information about the roadway (safe exit speed, distance between exits, and location of the motorist's exit). Two variables were selected to determine whether graphic guide signs can supply this information: the curvature of the exit arrows and the distance between the exits. Two interchanges were selected to display the characteristics. The 4 signs for each interchange (3 graphic, 1 conventional) are shown in Figure 4. The distance between the exits in the second concept is twice that in the third and fourth concepts; the third concept displays one or more curved exit arrows. The 2-projector, tachistoscopic technique was again used.

The results from 48 driver subjects (Table 4) indicated that the curved exit arrow resulted in significantly lower estimates ($p < 0.05$) of safe exit speed. Greater exit speeds were estimated for the conventional sign than for any of the graphic signs. The distance between the exits for graphic sign 1 was judged as significantly greater

Figure 1. Graphic and conventional sign concepts and interchanges used in tests.

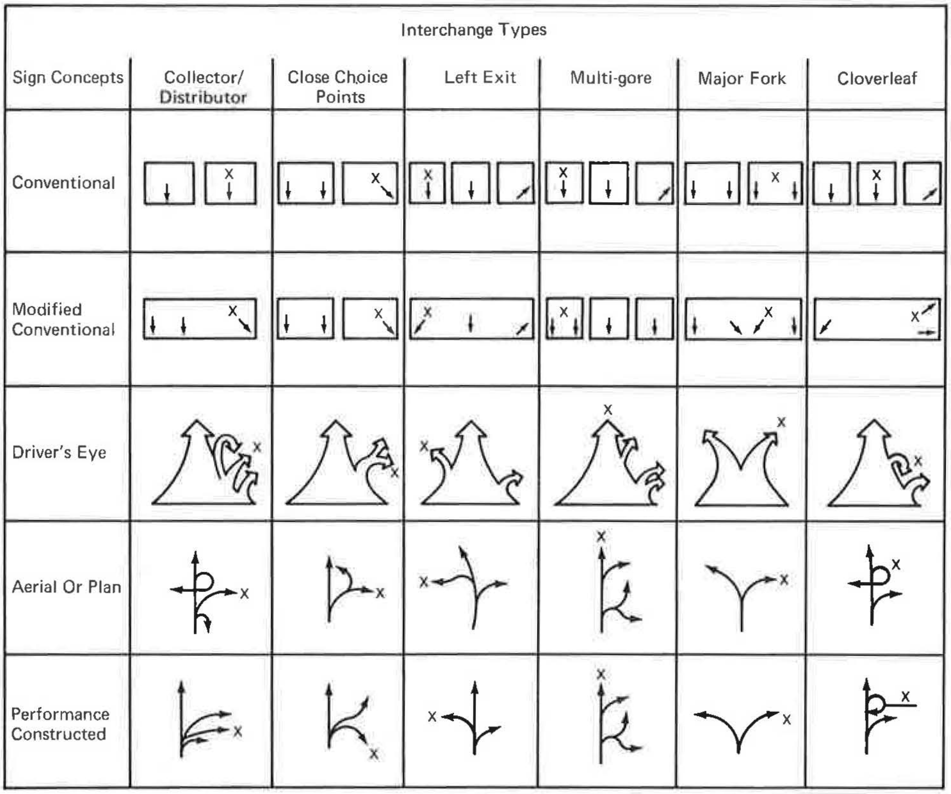

Figure 2. Roadway scene without and with guide-sign information on panel.

Table 1. Percentage of proper lane choices based on various sign concepts.

Interchange	Conventional	Modified Conventional	Driver's Eye	Aerial or Plan	Performance Constructed	S_{D_p}
Collector-distributor	—[a]	54	50[b]	70[b]	49[b]	0.098
Close choice points	88[b]	94	98[b]	96	92	0.048
Left exit	86	96	86	96	94	0.055
Multigore	88	88	78	82[c]	82[c]	0.072
Major fork	82	72[b]	88[b]	92[b]	92[b]	0.070
Cloverleaf	—[a]	78[b]	50[b]	54[b]	64	0.096

Note: Sample size = 51.

[a] Signs were discarded because they did not strictly conform to current standards.

[b] Higher percentage represents significantly better performance at 0.05 level compared to other sign similarly marked for that interchange.

[c] Only 1 sign tested because both were practically identical.

Table 2. Percentage of proper lane choices based on conventional and plan concepts.

Interchange	Conventional	Aerial or Plan	S_{D_P}
Collector-distributor	65	94[a]	0.08
Close choice points	54	92[a]	0.09
Left exit	69	80	0.09
Multigore	54	40	0.10
Major fork	64	80[b]	0.09
Cloverleaf	50	44	0.10

Note: Sample size = 50.

[a] $p < 0.01$. [b] $p < 0.10$.

Figure 3. Graphic and conventional sign concepts and interchange used in preference test.

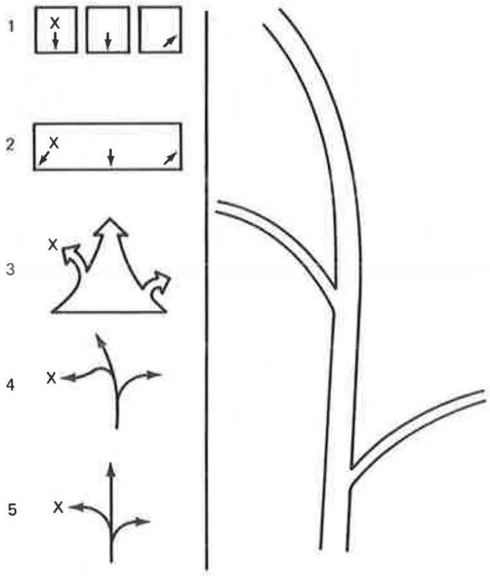

Table 3. Sign concept preferences.

Interchange	Conventional	Modified Conventional	Driver's Eye	Aerial or Plan	Performance Constructed
Collector-distributor	6	2	16	63	12
Close choice points	5	1	12	60	21
Left exit	12	8	13	43	25
Multigore	18	11	21	28	21
Major fork	8	8	25	18	42
Cloverleaf	8	1	3	74	14

Figure 4. Graphic and conventional signs used in roadway characteristic test.

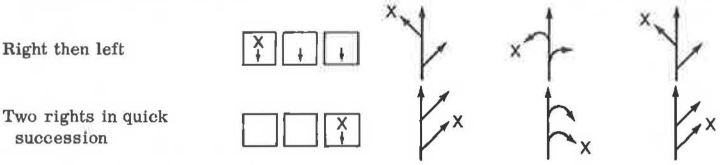

Table 4. Estimates of exit speed, exit distance, and correct exit based on sign concept.

Characteristic	Sign Concept	Exit Speed (mph) Mean	Exit Speed (mph) Standard Deviation	Miles Between Exits Mean	Miles Between Exits Standard Deviation	Respondents Identifying Their Exits (percent)
Right then left	Conventional	51	13.2	½	0.56	6
	Graphic 1	43	8.9	¾	0.59	79
	Graphic 2	31	6.7	½	0.49	77
	Graphic 3	42	9.5	½	0.49	58
2 rights in quick succession	Conventional	52	13.2	⅗	0.59	48
	Graphic 1	44	9.4	1	0.56	69
	Graphic 2	27	4.7	⅗	0.40	79
	Graphic 3	43	8.3	¾	0.45	69

($p < 0.05$) than for any of the other signs. A significantly greater percentage of the subjects correctly identified their exits (as the first or second exit) when they were shown the graphic guide sign rather than the conventional signs.

Interpretation of Performance Versus Preference Results—The mean preference ratings for the liked-best signs, the percentage choosing the correct lane, and the mean confidence ratings of subjects choosing the correct lane were pair-wise correlated over the tested signs. Preference and proper lane performance were not significantly related ($r = 0.07$). However, the dependencies inherent in the preference rating method and the small variance in proper lane performance would severely attenuate the correlation. Nevertheless, comparisons between the 2 sets of means reveal discrepancies that cast serious doubts on the use of preference ratings for selecting guide signs.

Mean preference and confidence rating were not significantly related ($r = 0.26$; $p < 0.2$). Again the correlation is restricted by the rating method employed.

The proper lane performance percentages were significantly related ($r = 0.53$) to mean confidence.

Function 5: Establish Guidelines for Graphic Guide Signs

Based on the preceding, a series of guidelines was established for graphic guide signs. The general guideline is that graphic guide signs have some application for depicting geometric limitations of an interchange. This is exemplified most clearly in their application to lane drops. They also appear to have utility in communicating exit speed if the curvature of the exit is indicated by the graphic. In addition, graphic guide signs can improve lane positioning where there are close sequential choice (gore) points and, possibly, major forks.

A characteristic that is worthy of consideration for evaluation under highway conditions is the utilization of graphics at interchanges where it is difficult to rectify a mistake.

CONCLUSIONS AND RECOMMENDATIONS

A laboratory technique to measure highway guide signs was developed. This technique can differentiate signs by determining whether individuals can select the proper lanes for their destinations. A sign interpretation technique indicated that graphic guide signs can communicate roadway characteristics (such as lane drops and exit speeds) to the driver. Sign preference data should be used with caution because the preference data did not relate to proper lane positioning data.

Graphic guide signs can improve lane positioning where there are close choice points (gores) and, possibly, for collector-distributor and major fork interchanges. They can provide information on the relative speed of exit ramps and the distance between ramps and can facilitate the identification of the driver's exit.

It is recommended that the findings and guidelines developed in this study be verified with on-the-road studies. There is a need to develop techniques to determine the quantitative and qualitative characteristics of interchanges requiring graphic or other improved guide signs. If the laboratory techniques for measuring sign effectiveness are verified in the field, the traffic engineer will have a quick, inexpensive technique to evaluate new sign concepts without the expense and possible danger of on-the-road installations.

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EVALUATION OF DIAGRAMMATIC GUIDE SIGNS

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A laboratory evaluation was made of diagrammatic signs for a freeway cloverleaf intersection, a lane drop, a multiple-split ramp, a left ramp downstream from a right ramp, two right ramps in quick succession, and a major fork. The evaluation included a comparison of diagrammatic and conventional signs, based on the speed and accuracy of the subjects' lane selections. Conventional signs were found slightly more effective overall than the experimental diagrammatic signs. They produced fewer lane-placement errors and errors on exit lanes, and they were more quickly responded to than diagrammatic signs. The conventional signs were also preferred by the subjects. In none of the 6 types of interchanges tested did diagrammatic signs provide better performance than conventional signs. Of the diagrammatic signs tested, the one showing a large exit arrow gave the best performance. Consideration might be given to increasing the size of the conventional exit arrow. The major fork symbol also showed up fairly well. The results of this study apply only to the sign designs tested. Other diagrammatic signs on other types of road may possibly be more successful.

•RECENTLY, wide interest has been shown in the use of diagrammatic freeway signs. Diagrammatic signs have been installed on highways in New Jersey, Virginia, Wyoming, Maryland, Oregon, and Ohio. Twenty states now have such signs. Diagrammatic guide signs have also been recommended in the Manual on Uniform Traffic Control Devices for intersections at grade (5, p. 122), for cloverleafs (5, pp. 124, 139), and for directional interchanges (5, p. 139). Simple diagrammatic warning signs are also recommended for curves, winding roads, road crossings, side roads, and T- and Y-intersections.

Because diagrammatic signs are being considered for adoption on freeways, they should be given a thorough research assessment. They should be tested against the conventional designs now on the road. The laboratory assessment of diagrammatic signs described here was carried out during the summer of 1971, and the final report was submitted in September 1971. On-the-road studies of diagrammatic signs have been carried out by Hanscom (3) and Roberts (4) among others.

ADVANTAGES OF LABORATORY SIGN TESTING

Laboratory tests have several important advantages in sign evaluation. Such tests are inexpensive. The materials for this study were prepared from ordinary black and white photographs of the highway, on which artificial sign messages were superimposed. The presentation equipment included a simple slide projector and a reaction timer. Laboratory tests can be carried out rapidly. Results can be obtained in weeks; a highway study would require months, or even years. Another often overlooked advantage of a laboratory study is that conditions can be controlled. In field studies on the road, we must take drivers as they come. In the laboratory, drivers can be trained to any required level of experience, and precisely the same traffic problem can be presented to each subject. Nevertheless, it is important that results obtained in the laboratory be verified in the field to guard against the possible artificiality of the laboratory situation.

The present study is a follow-up of research carried out by Serendipity, Inc., for the National Highway Traffic Safety Administration (1). In that study, volunteer subjects

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recruited at the Smithsonian Institution were shown projected slides of conventional and diagrammatic freeway signs. They were asked to indicate on an answer sheet the highway lane they should be in to reach a preassigned destination. On 4 of the 6 interchanges tested, drivers selected the correct lane more frequently when diagrammatic signs were displayed. However, they reported more confidence in their choices when they viewed conventional signs in 18 of the 29 cases (signs) tested. Results of the Serendipity study have been widely interpreted as an endorsement of the use of diagrammatic signs.

In this study, a number of modifications were made to the Serendipity testing procedure. Drivers were tested individually rather than in groups. Single testing ensured that subjects were not distracted, that they understood the instructions, and that all subjects viewed from the same position. In the previous study, only one destination was selected for testing at each intersection. Because interchange signs show both left- and right-turn destinations, both destinations were studied here. Driver performance was more thoroughly rated. Times were taken of reactions to the signs. The speed of a driver's reaction to a sign is considered to be particularly important in closely spaced urban interchanges.

EQUIPMENT

Subject's Cubicle

The subjects viewed the signs in a 9- by 11-ft closed cubicle. At a distance of $8\frac{1}{2}$ ft, the 5.0-in. high letters of the projected signs subtended a visual angle of 17 min and could be easily read. The projector and reaction time equipment were housed in the experimenter's compartment adjacent to the subject's cubicle.

Signs

The subjects made lane-choice judgments on the following types of interchange: (a) lane drop (Wilson Bridge interchange going into Alexandria), (b) multiple-split ramp (Shirley Highway going north into I-495), (c) left ramp downstream from right ramp (I-495 going east into Shirley Highway), (d) 2 right ramps in quick succession (Glen Echo exit of I-495 going toward Virginia), (e) major fork (fork of I-495 and I-70 to Frederick), and (f) cloverleaf (exit of I-495 going east into the Baltimore-Washington Parkway). These interchanges include the more difficult freeway signing situations in the Washington, D. C., area.

The projected slides viewed by the subjects showed black and white photographs of actual sign locations on which colored drawings of signs were superimposed (Fig. 1). The diagrammatic signs duplicated the Serendipity designs; the conventional signs were drawn in conformity with the U. S. Manual on Uniform Traffic Control Devices. The artificial destinations on the signs all contained exactly 9 letters. The same destinations were used on the 3 to 6 consecutive signs of each intersection. The photographs of the highway were taken on the center lane at a distance of 200 ft from the sign. Lane numbers were printed on the road surfaces of the slides to aid the subject in making his choices.

Scoring Key

A sign's effectiveness was evaluated on the basis of the subject's lane selections and reaction times to the sign. A great deal of attention was paid to the scoring key, which was used to grade the subject's lane choices.

The key finally developed was grounded on the following rules:

1. At the advance guide sign, the driver was judged correct if he selected either the first or the second lane (at this point it was not considered necessary for the driver to be in the exit lane);
2. The driver was expected to be in the exit lane when the sign indicated his exit; and
3. He was expected not to be in the exit lane when an exit destination other than his was on the sign.

The scoring key of the first interchange (Fig. 1) may be given as an illustration of these principles. Bladworth was given as the destination to be reached. The first advance warning sign indicated both Bladworth and Tabernash exits on the 3-lane highway. The first (right) and second (middle) lanes were graded correct. The next sign indicated a Roachdale exit. Because this was not the driver's destination, only the second lane was judged correct. The next 3 signs indicated the Bladworth exit. Only the first (exit) lane was correct.

The Grandview destination was given at the next interchange (Fig. 2). At the advance warning sign, either lane of the 2-lane highway was accepted. The next sign indicated an exit for Hornbrook. The Grandview driver was expected to be in the left, nonexit lane. At the third sign, showing a Grandview exit, the driver was expected to be in the exit lane.

Other interchanges are shown in Figures 3, 4, 5, and 6.

SUBJECTS

Subjects included housewives, students, and drivers obtained from the local state employment office. All subjects demonstrated 20/20 or better corrected vision in both eyes, and all held valid driving licenses. There were 28 men and 32 women (60 subjects in all) in the 2 phases of the study. The initial familiarity advantage of the conventional signs was offset by considerable practice on both types of signs. Familiarity with the Washington, D. C., Beltway (I-495) did not affect results. Subjects did not recognize the Beltway interchanges with the signs altered.

PROCEDURE

The experiment consisted of 2 phases, in each of which 30 subjects were tested, as follows:

Session	Phase 1	Phase 2
Practice	Destinations A	Destinations B
Test 1	Destinations B	Destinations A
Test 2	Destinations B	Destinations A

If the destination led to the right in phase 1, it was to the left in phase 2, and vice versa. In this manner, all sign destinations were tested. It was not necessary to test the straight ahead case.

At the start of a session, the subject sat viewing the screen in the isolation compartment. He was told to push the button indicating his lane choice as quickly as possible. The first destination (say, Bladworth) was presented on a preliminary slide. The subject repeated the destination aloud to ensure that he knew his goal. The first and succeeding road signs were then shown. In each case, the subject signified his lane choice by pressing the appropriate button. The experimenter tallied the subject's lane choice and reaction time and pushed the 2 buttons to clear the displays and project the next sign. After the subject had viewed all the signs of an intersection, testing continued on the next destination and intersection.

The practice session of phase 2 had the same destinations as the test sessions of phase 1; and, similarly, the practice session of phase 1 had the same destinations as phase 2. By this procedure, the subjects became familiar with the sign types but not with the particular problems asked in the test series. The first 15 subjects viewed diagrammatic signs in each series before conventional signs; the next 15 subjects viewed conventional signs first. Each subject went through 3 complete series of 58 presentations each and, therefore, made a total of 174 lane-choice judgments. It had been shown in preliminary studies that performance showed no improvement in longer experimental sessions.

RESULTS

General Comparison of Diagrammatic and Conventional Signs

Certain practical considerations must be kept in mind as one interprets the results of this evaluation. Before replacing a conventional sign, a diagrammatic sign must

Figure 1. Conventional signs (left) and diagrammatic signs (right) at interchange 1.

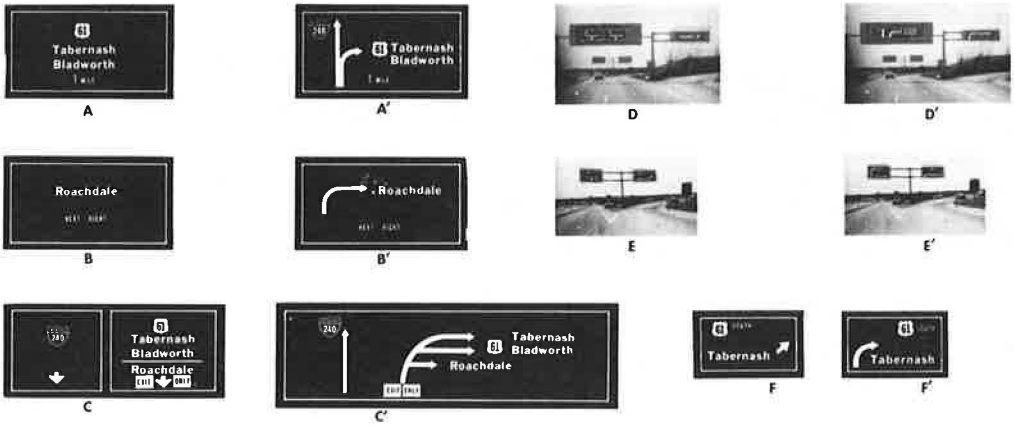


Figure 2. Conventional signs (left) and diagrammatic signs (right) at interchange 4E.

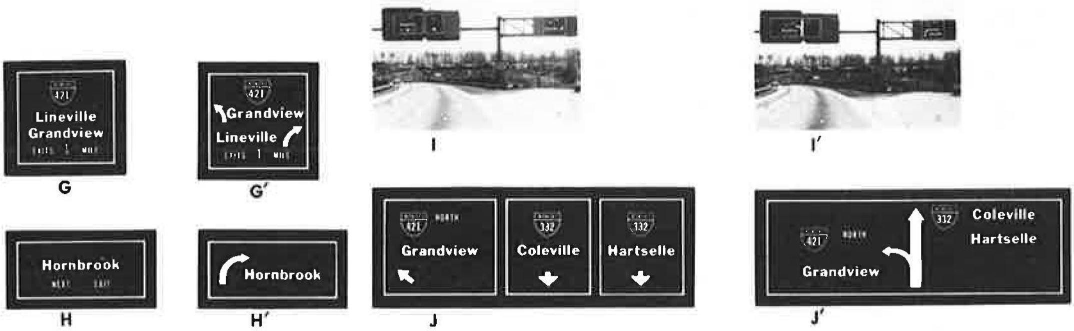


Figure 3. Conventional signs (left) and diagrammatic signs (right) at interchange 4N.

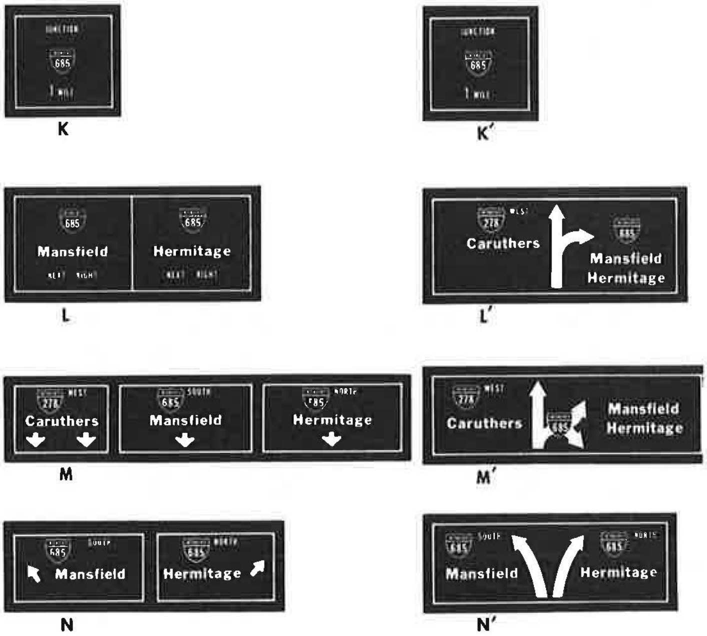


Figure 4. Conventional signs (left) and diagrammatic signs (right) at interchange 16.

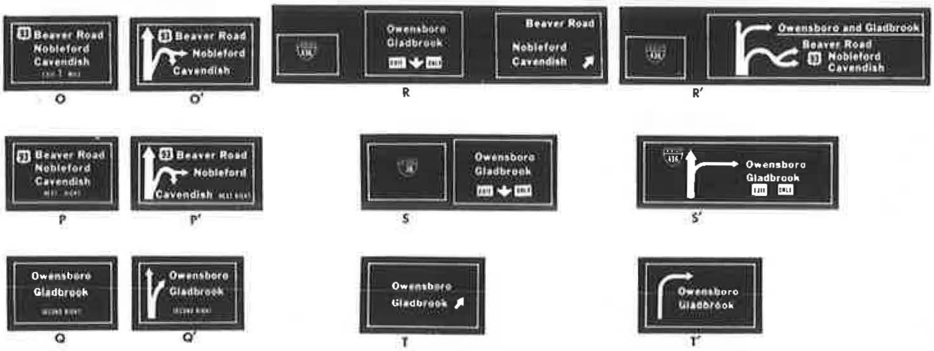


Figure 5. Conventional signs (left) and diagrammatic signs (right) at interchange 17.

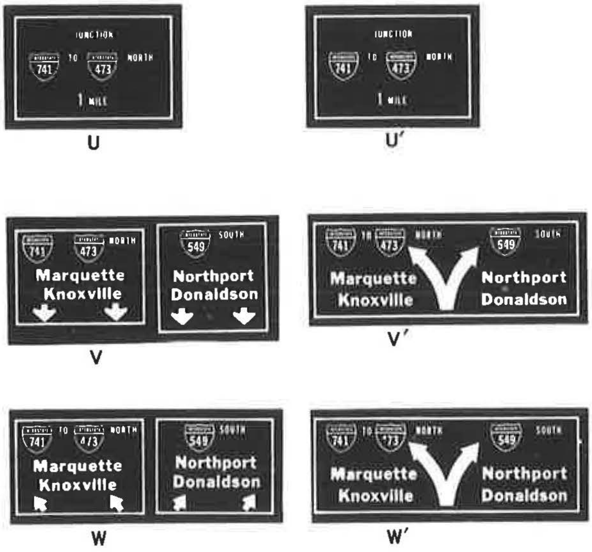
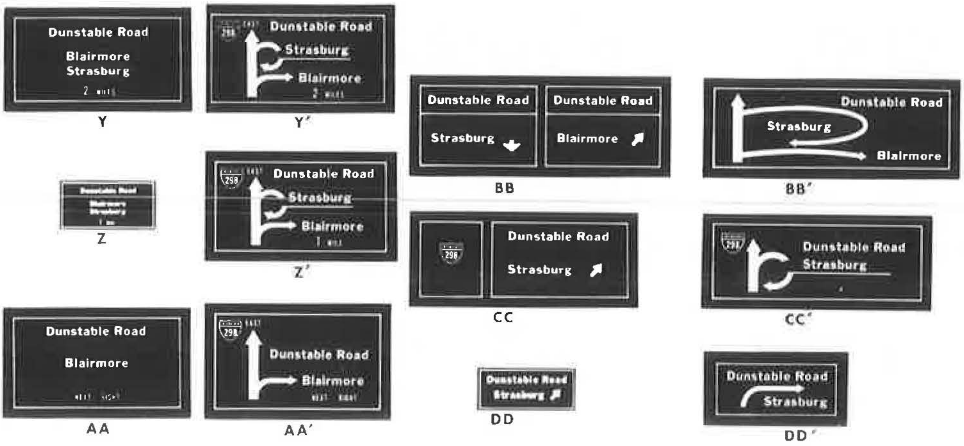


Figure 6. Conventional signs (left) and diagrammatic signs (right) at interchange 29.



provide a convincingly better performance. If a novel sign is merely as good as its conventional counterpart, there would be little reason to undergo the expense and loss of time of the changeover and the inconvenience of reeducating the public to the new system. To warrant adoption, a new signing system must demonstrate a clear superiority over the one in use.

A detailed analysis of errors and reaction times to the signs is given in Tables 1, 2, 3, and 4. Phase 1 results refer to one set of destinations; Phase 2 refers to the alternate destinations. Each number given in Tables 3 and 4 represents the mean reaction times of 30 subjects to the 3 to 6 signs at an interchange. The destinations used in the practice trials of phase 1 were used in the test trials of phase 2, and vice versa. The average column summarizes the results of the 2 phases. The final test (test 2) represents practiced driver performance.

The overall comparison of errors and reaction times of diagrammatic and conventional signs is shown in Figure 7. The error scale is given on the left; reaction time is given on the right. The points shown in Figure 7 are totals and averages given in the last columns of Tables 1 and 3. Each point represents 29 responses for each of the 60 subjects, or 1,740 reactions in all. The slope of the functions, both diagrammatic and conventional performance, improved with practice. The improvement in conventional signs may be ascribed to the subjects' adjustment to the test routine. The format of conventional highway signs was, of course, familiar to the subjects. Improvements in diagrammatic sign performance reflect both adjustment to the test routine and familiarization with the format of the signs. Although performance on both types of signs improved, lane selection is superior, and reaction time is, on the average, shorter on the conventional signs in all series. At the end of the session, each subject was asked which kind of sign he found easier to use. The answers are given in Table 5. Of the 60 subjects, 26 (43 percent) preferred the conventional signs, and 16 (27 percent) preferred the diagrammatic signs.

Signing for Particular Interchanges

Although the diagrammatic signs tested were on the average not so effective as conventional signs, the possibility remains that some may be more suitable for a particular interchange type.

The results given in Tables 1, 2, 3, and 4 would not support use of diagrammatic signs on any of the interchanges tested. On the second test, which represents practiced driver performance, diagrammatic signs excelled conventional signs on only the following 4 (of 24) comparisons: On interchange 16, 48 errors were made on diagrammatic signs and 49 on conventional signs; on interchange 29, no errors were made on the diagrammatic exit sign, and 1 was made on the conventional exit sign; on interchange 1, average reaction time to diagrammatic signs was 2.48 sec and 2.58 sec to conventional signs; and on intersection 2, diagrammatic signs required 2.54 sec and conventional signs 2.55 sec. None of these differences is large enough to achieve statistical or practical significance.

Particular Diagrammatic Designs

The question remains whether any of the diagrammatic signs tested were outstanding. Results of the second test after practice, sorted by design, are given in Table 6. Symbol 1, the single-arrow design that indicated an exit, appeared in 6 cases. Symbol 2, the double arrow with 1 alternative straight ahead, appeared 6 times, and so on. Table 6 gives the total number of errors made on diagrammatic and conventional signs, the average reaction times, and the significance level of the difference in average reaction times among signs.

The single arrow showed up best of the diagrammatic symbols tested. Thirty-seven errors were made on the diagrammatic arrow, and 52 were made on corresponding conventional signs. In 6 of the 10 cases listed, the reaction time to diagrammatic signs was shorter. Of these, 2 reached significance at least to the 0.05 level (t-test for correlated measures, N = 30, 3). Consideration might be given to increasing the size or prominence of the arrow symbol on freeway exit signs.

Table 1. Errors made at each interchange.

		Interchange						
Session	Sign	1	4E	4N	16	17	29	Total
Practice								
Phase 1	Diagrammatic	0	5	0	2	2	1	10
	Conventional	0	0	0	0	2	0	2
Phase 2	Diagrammatic	0	0	0	1	1	4	6
	Conventional	0	0	0	0	0	0	0
Total	Diagrammatic	0	5	0	3	3	5	16
	Conventional	0	0	0	0	2	0	2
Test 1								
Phase 1	Diagrammatic	0	0	0	0	0	0	0
	Conventional	0	2	0	0	0	0	2
Phase 2	Diagrammatic	0	3	1	0	1	0	5
	Conventional	0	0	0	0	0	0	0
Total	Diagrammatic	0	3	1	0	1	0	5
	Conventional	0	2	0	0	0	0	2
Test 2								
Phase 1	Diagrammatic	0	0	0	0	0	1	1
	Conventional	0	0	0	0	0	0	0
Phase 2	Diagrammatic	0	5	2	0	0	0	7
	Conventional	1	1	0	0	0	0	2
Total	Diagrammatic	0	5	2	0	0	1	8
	Conventional	1	1	0	0	0	0	2

Table 2. Errors made at critical exits.

		Interchange						
Session	Sign	1	4E	4N	16	17	29	Total
Practice								
Phase 1	Diagrammatic	16	19	12	32	4	40	123
	Conventional	17	17	11	56	3	18	122
Phase 2	Diagrammatic	29	13	2	38	1	4	87
	Conventional	15	14	3	30	1	5	68
Total	Diagrammatic	45	32	14	70	5	44	210
	Conventional	32	31	14	86	4	23	100
Test 1								
Phase 1	Diagrammatic	27	15	4	33	0	4	83
	Conventional	19	14	6	38	0	6	83
Phase 2	Diagrammatic	24	26	17	21	3	39	130
	Conventional	13	29	7	17	2	14	82
Total	Diagrammatic	51	41	21	54	3	43	213
	Conventional	32	43	13	55	2	20	165
Test 2								
Phase 1	Diagrammatic	21	16	9	28	1	4	79
	Conventional	21	14	4	28	0	7	74
Phase 2	Diagrammatic	29	27	12	20	0	29	117
	Conventional	19	23	4	21	1	15	83
Total	Diagrammatic	50	43	21	48	1	33	196
	Conventional	40	37	8	49	1	22	157

Table 3. Reaction times (sec) at each interchange.

		Interchange						
Session	Sign	1	4E	4N	16	17	29	Avg
Practice								
Phase 1	Diagrammatic	3.94	3.55	4.06	3.94	3.81	4.11	3.90
	Conventional	3.32	3.32	3.46	3.54	3.51	3.01	3.36
Phase 2	Diagrammatic	3.65	3.10	2.85	3.24	2.82	2.90	3.14
	Conventional	3.13	3.06	2.62	2.89	2.79	2.81	2.90
Avg	Diagrammatic	3.80	3.33	3.46	3.59	3.32	3.51	3.50
	Conventional	3.22	3.19	3.04	3.22	3.15	2.91	3.12
Test 1								
Phase 1	Diagrammatic	2.94	2.84	2.81	3.01	2.78	2.97	2.89
	Conventional	2.69	2.82	2.43	2.83	2.71	2.51	2.67
Phase 2	Diagrammatic	2.89	2.77	2.85	2.73	2.87	3.34	2.93
	Conventional	2.51	2.53	2.69	2.57	2.61	2.45	2.55
Avg	Diagrammatic	2.92	2.81	2.83	2.87	2.83	3.16	2.91
	Conventional	2.60	2.68	2.56	2.70	2.66	2.48	2.61
Test 2								
Phase 1	Diagrammatic	2.41	2.50	2.28	2.59	2.25	2.41	2.41
	Conventional	2.84	2.59	1.94	2.45	2.25	2.21	2.38
Phase 2	Diagrammatic	2.54	2.57	2.53	2.53	2.30	2.84	2.58
	Conventional	2.32	2.50	2.31	2.52	2.18	2.23	2.35
Avg	Diagrammatic	2.48	2.54	2.41	2.56	2.28	2.63	2.48
	Conventional	2.58	2.55	2.13	2.49	2.22	2.22	2.36

Table 4. Reaction times (sec) at critical exits.

		Interchange						
Session	Sign	1	4E	4N	16	17	29	Avg
Practice								
Phase 1	Diagrammatic	2.70	3.80	3.82	2.40	4.07	2.36	3.19
	Conventional	2.15	3.02	2.91	2.06	3.88	1.73	2.63
Phase 2	Diagrammatic	2.04	2.12	2.28	1.84	2.40	2.78	2.24
	Conventional	1.72	2.12	2.03	1.66	2.52	1.89	1.99
Avg	Diagrammatic	2.37	2.96	3.05	2.12	3.24	2.57	2.72
	Conventional	1.94	2.57	2.47	1.86	3.20	1.81	2.31
Test 1								
Phase 1	Diagrammatic	1.90	2.51	2.36	1.98	2.61	2.72	2.35
	Conventional	1.67	2.11	1.91	1.71	2.89	1.64	1.99
Phase 2	Diagrammatic	1.83	2.87	2.50	1.78	3.04	1.85	2.31
	Conventional	1.60	2.53	2.46	1.62	2.67	1.50	2.06
Avg	Diagrammatic	1.87	2.69	2.43	1.88	2.83	2.29	2.33
	Conventional	1.64	2.32	2.19	1.67	2.78	1.57	2.03
Test 2								
Phase 1	Diagrammatic	1.52	1.93	1.85	1.75	2.21	2.13	1.90
	Conventional	1.57	1.72	1.58	1.49	1.97	1.64	1.66
Phase 2	Diagrammatic	1.96	2.80	2.40	1.59	2.40	1.69	2.14
	Conventional	1.66	2.00	2.10	1.61	1.99	1.28	1.77
Avg	Diagrammatic	1.74	2.37	2.13	1.67	2.31	1.91	2.02
	Conventional	1.62	1.86	1.84	1.55	1.98	1.46	1.72

Figure 7. Improvement in subjects' performance with practice.

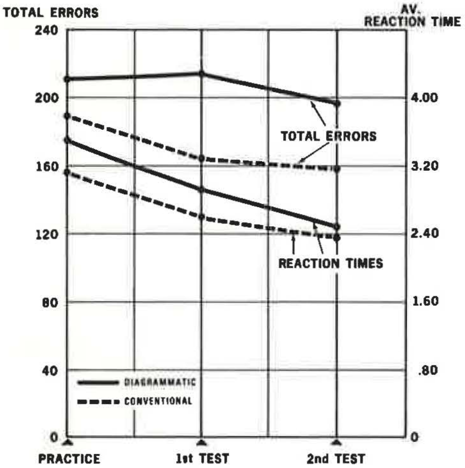


Table 5. Preferences for diagrammatic and conventional signs.

	Conventional Sign		Diagrammatic Sign		No Preference		Total	
Phase	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1	14	46	8	27	8	27	30	100
2	12	40	8	27	10	33	30	100
1 and 2	26	43	16	27	18	30	60	100

There is some support for the use of symbol 3, the forked-arrow, at interchange 17, sign V′. Only 1 error was made on the diagrammatic and on the conventional sign, and the diagrammatic sign gave shorter reaction times.

DISCUSSION OF RESULTS

These results, which do not generally favor substituting diagrammatic for conventional signs, appear in contradiction to the findings of the Serendipity study, and some explanation of the discrepancy seems called for. It will be recalled that in the Serendipity study the correct lane was considered to be the right (exit) lane in all cases, although the scoring method is not given in the report. The scoring key used here, which was worked out after considerable discussion, may perhaps be more defensible than the Serendipity key. (See the discussion given above on the scoring key.)

Although the scoring of a "correct" lane may be controversial, the other assessment measures are less so. There can be little question that a sign that exits the driver at his destination ramp is superior to one that does not. A good sign should also permit the driver to quickly extract the essential information. The driver's preference for one sign over another should also be considered when sign designs are evaluated. On these additional measures, conventional signs generally showed up as more effective than diagrammatic signs.

The reaction time results may be explained in terms of how the driver makes his lane-choice decision. In the case of conventional signs, it may be suggested that the driver must (a) find his destination on the sign and (b) select his lane by observing which lane his destination arrow points to. Usually the lane pointed to by the arrow was clearly and easily recognized. For diagrammatic signs, the driver must (a) locate his destination on the sign, (b) interpret the road geometry represented by the lines and arrows, and (c) make a lane choice based on the geometry.

If this interpretation is accepted, lane-choice selection is simpler and more direct and rapid when conventional signs are viewed. However, the diagrammatic display of road geometry may have advantages in certain situations, particularly when the geometry violates the drivers' expectations. Such might be the case at a T- or Y-intersection or at a left off-ramp where visibility is poor.

DIRECTION OF FUTURE RESEARCH

In future research, the requirements of directional guide signs should be detailed. The requirement of the first sign, called advance guide, is to alert the driver of the coming intersection. At this point, the driver is asking, "Does the intersection concern me?" An advance guide sign must, therefore, be large and clear and must present the choices ahead in simple, direct fashion. It need not place the drive in the outermost lane, unless intersections are closely spaced. An ideal advance warning might be a loud auditory signal; although such a signal may be impractical for other reasons.

The second advance guide sign tells the driver what he is expected to do. The sign should place the driver in the correct lane and tell him the distance to the intersection. Finally, the critical exit sign should get the driver off the road. It should be placed before the exit, and the required action should be clearly indicated. Results of this study suggest that a large arrow may be effective.

Whatever the requirements of the various types of signs—and one may disagree with the requirements stated above—they must be explicitly stated if research is to be effective. A clear statement must be made of what the sign design is intended to accomplish. Otherwise, design after design will be tested without a clear idea of the improvement accomplished.

SIGN CONTENT AND ROAD GEOMETRY

The problem of sign content is related to the problems of sign format considered here. When asked what destination should be on a sign, drivers usually name their own: "Seven Corners," "Bethesda," "Wheaton," and so forth. If every local destination is listed, the sign will be cluttered. On the other hand, if a very limited number of destinations and routes are given, the sign will fail to give the required information.

Because the number of messages that can be placed on a sign is limited, the driver must adapt to the signing system. In unfamiliar areas, he must look up intermediate towns and routes and otherwise do his "homework." A certain amount of frustration seems built into the system. In some cases, the attractiveness of diagrammatic signs seems to have been based on the difficulty of providing information on conventional signs. An enormous amount of information can be placed on a map (diagrammatic) display, but a sign with too much information is difficult to read. There is no evidence that the driver's ability to absorb and respond to information is increased when he views a diagrammatic sign. A cluttered sign is cluttered, regardless of its format.

Signing problems are also related to problems of road geometry. A difficult intersection is usually difficult to sign. Closely spaced interchanges, left exits, and unusual movements of traffic are all difficult to sign. Changing a sign is cheaper than constructing a road, but the fact remains that correcting the geometry may be a better and more fundamental solution to a traffic problem.

EUROPEAN APPLICATIONS OF DIAGRAMMATIC SIGNS

The extensive use of diagrammatic signs on European roads has encouraged the search for applications to U. S. freeways. Examples of European diagrammatic signs, observed by the author in a recent trip, are shown in Figure 8. The first Dutch sign (sign A) indicates that Amsterdam, Schiphol Airport, and the town of Utrecht are ahead and that Schalkwuk is to the right. Sign B indicates that the driver should take the right lane if he is going to the center of the city and the left lane if he is going to Zandovoort or Den Haag. Sign C says that there is a road to the right to Sassenheim and Amsterdam, and the driver should stay in the right lane. These signs do not contain route or road name information. They seem simpler and less cluttered than many American diagrammatic signs.

The French sign showing the road to Orleans (sign D) also presents a simple choice. The lane separations are suggested by white slashes. A British circle or "roundabout" is shown in sign E. The break in the ring indicates that the driver should not turn in that direction. The horizontal road intersections to Bagshot and Windsor are neatly shown. A more complex British circle is shown in sign F. Although route numbers appear, the overall effect is neat and interpretable.

The French circle (sign G) shows the Paris and Orleans destinations in large letters; the Rambouillet exit and the center of town are in smaller letters. Signs H and I warn the driver of complex turns ahead. These signs are simple and easy to read.

It is helpful to remember that European roads originated as carriageways leading from one town to the next. The amount of information needed to be displayed is limited, and traffic is slow enough to permit the driver time to read the signs. In contrast, American freeways cross prominent routes that themselves go toward large towns. Route, city, and road name information are often shown on the sign, and the driver reads the sign at high speed. There is a temptation to place a great deal of information on our diagrammatic signs and thereby to solve the designer's rather than the driver's problems.

SUMMARY AND FINDINGS

This paper presents a laboratory assessment of diagrammatic sign designs being considered for use on U. S. freeways. Diagrammatic signs were compared with the conventional guide signs now on the road. The subjects viewed projected scenes of the Capital Beltway and indicated as quickly as possible the proper lane to be in to reach a preassigned destination. The signs tested were made by superimposing diagrammatic and conventional sign drawings on actual photographs of the highway. The road scenes presented the signs of a cloverleaf intersection, a lane drop, a multiple-split ramp, a left ramp downstream from a right ramp, 2 rights in quick succession, and a major fork. The study is a follow-up of one carried out by Serendipity, Inc., under contract to the Highway Traffic Safety Administration. Certain improvements have been made here in the Serendipity procedure. Drivers were individually tested, and the effectiveness of the signs was more thoroughly assessed.

Table 6. Speed and accuracy of reactions to types of sign symbols.

Sign Symbol	Inter-change	Sign	Phase	Total Errors: Diagrammatic	Total Errors: Conventional	Avg Reaction Time (sec): Diagrammatic	Avg Reaction Time (sec): Conventional	Statistical Significance[a]
1	1	B′	1	7	10	2.26	2.24	
			2	13	13	2.21	2.68	0.05
	1	E′	1	0	0	2.18	2.28	
			2	0	1	1.96	1.66	0.05
	1	F′	2	0	0	1.52	1.57	
	4E	H′	1	14	14	2.55	2.60	
			2	3	14	2.04	2.47	0.05
	16	T′	1	0	0	1.75	1.49	
			2	0	0	1.59	1.61	
	29	DD′	2	0	0	1.69	1.28	0.01
2	1	A′	1	0	0	2.44	2.16	
			2	0	0	2.63	2.18	0.01
	4N	L′	1	3	3	2.40	2.09	
			2	3	4	2.58	2.48	
	16	Q′	1	15	12	2.52	2.49	
			2	11	13	2.69	2.39	
	16	S′	1	4	5	2.78	2.89	
			2	3	5	2.67	3.24	
	29	AA′	1	0	0	1.87	1.89	
			2	6	12	2.71	2.87	
	29	CC′	1	0	0	3.30	3.25	
			2	13	3	3.96	2.36	0.01
3	4N	N′	1	0	0	1.85	1.58	
			2	2	4	2.40	2.10	0.05
	17	V′	1	1	0	2.42	2.75	
			2	0	1	2.36	2.40	
	17	W′	1	0	0	2.21	1.97	
			2	0	0	2.40	1.99	0.05
4	4E	J′	2	5	1	2.80	2.00	0.01
5	4E	G′	1	2	0	2.22	2.42	
			2	1	0	2.75	2.30	0.05
6	4N	M′	1	6	1	2.86	2.04	0.01
			2	7	0	3.09	2.46	0.05
	16	O′	1	3	3	2.57	2.47	
			2	0	1	2.43	2.75	
	16	P′	1	2	3	2.10	2.05	
			2	0	0	2.13	2.12	
7	29	Y′	1	0	1	2.57	2.17	0.05
			2	1	0	3.38	2.68	0.05
	29	Z′	1	3	6	2.10	2.16	
			2	8	0	2.44	2.29	
	29	BB′	1	1	0	2.13	1.64	
			2	1	0	3.06	1.92	0.01
8	1	D′	1	5	5	2.76	3.25	
			2	1	3	2.98	2.05	0.01
9	16	R′	1	4	5	3.80	3.34	
			2	6	2	2.67	3.02	0.01
10	1	C′	1	9	6	3.33	3.34	
			2	15	2	2.98	3.07	
11	4E	I′	1	0	0	1.93	1.72	
			2	18	8	2.69	3.23	0.05

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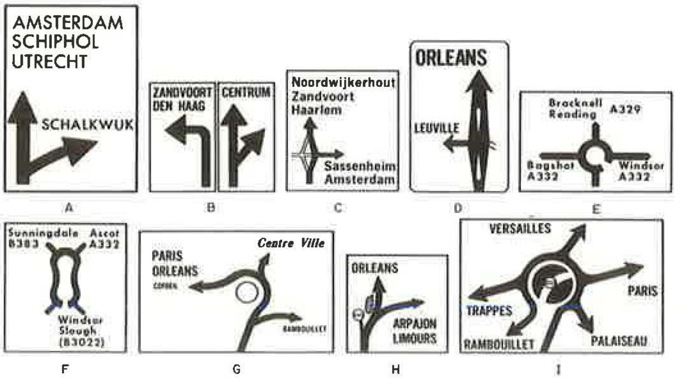
[a] If no value is given, not statistically significant.

Figure 8. European diagrammatic signs.



A B C D E

F G H I

On the basis of the subject drivers' reactions, the following findings are reported.

1. The conventional signs tested were on the whole slightly more effective than the experimental diagrammatic signs. They produced fewer errors and were more quickly responded to than diagrammatic signs. The conventional signs were also preferred by the subjects to diagrammatic signs.
2. In none of the six types of interchanges tested did the diagrammatic signs provide better lane placement or shorter response times than the conventional signs.
3. The diagrammatic symbol showing a large exit arrow showed up best of the diagrammatic signs tested. Consideration might be given to increasing the size of the conventional exit arrow.

The problems of sign content and road geometry were briefly discussed in their relation to sign format. It is suggested that thought be devoted to determining the driver's requirements in dealing with signs. To make a valid evaluation of signs, one must have a clear idea of what the sign is intended to accomplish.

Several cautions must be observed in the interpretation of the results of this study. The findings are limited to Serendipity sign designs applied to freeway intersections. We know that diagrammatic signs such as arrows and T- and Y-intersection signs are widely used on American roads and are endorsed in the Manual on Uniform Traffic Control Devices. The diagrammatic signs illustrated in the text are well accepted in Europe. European low-speed highways and clear destinations may lend themselves to diagrammatic applications better than U. S. freeways do. European diagrammatic signs also appear less cluttered than many American designs.

Finally, it must be remembered that these results have been obtained in the laboratory. They should be checked, if possible, against the results of field evaluations of diagrammatic signs.

ACKNOWLEDGMENT

Acknowledgment is made of the valuable assistance of John Fegan and Kiran Grover in collecting the data and analyzing results of this study.

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DIAGRAMMATIC SIGN STUDY

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Diagrammatic signs offer inherent improvements in road sign communication. Motorists are provided with more complete information on exits without additional words. The findings of this study show an improvement in exiting maneuvers after diagrammatic signs were installed and after lane lines were added to the diagrams on northbound I-287 at the left exit to westbound US-22. It is recommended that further evaluation of diagrammatic signing be carried out for a variety of exit configurations and for a whole series of interchanges. Serious consideration should be given to including the diagrammatic concept in new standards.

•THE USE of diagrammatic signs has been suggested as a method to reduce confusion at exits on the Interstate highway system. In 1968, the Special Subcommittee on the Federal-Aid Highway Program of the Committee on Public Works of the U.S. House of Representatives, known as the Blatnik Committee, took 16-mm movies and 35-mm stills of traffic approaching various exits at the interchange of I-95 and I-495 in Washington, D.C. The films show that a large number of vehicles swerve, stop, and back in the exit gore areas. The committee members generally assumed that the erratic behavior found was a result of confusion and that inadequate signing or road geometry or both were part of the problem. The erratic or unusual maneuvers shown in the films were considered to be symptomatic of both a hazardous situation and an annoyance to many motorists. The frequency of these maneuvers, it was felt, might be reduced by the installation of signs that will more adequately serve the needs of unfamiliar as well as familiar motorists.

The concept of using diagrams in signs is not new. The British have installed several signs of this type with apparent success. Symbolic warning signs have been used extensively in the United States and other countries.

The Federal Highway Administration's Office of Traffic Engineering had diagrammatic signs installed at the I-95 and I-495 interchange in Washington, D.C., and the engineers compared before-and-after frequencies of unusual maneuvers. They concluded that the comparison was not valid because of a difference in the proportion of "unfamiliar" motorists between the 2 study periods.

The FHWA requested that states carry out similar projects for a more thorough evaluation of freeway diagrammatics. In cooperation with the FHWA, the Division of Research and Development of New Jersey's Department of Transportation designed and had installed a system of these signs on northbound I-287 at US-22 in northcentral New Jersey.

SITE SELECTION

The interchange of northbound I-287 with US-22 was chosen from a careful investigation of 6 interchanges on the Interstate highway system in New Jersey. Aerial and on-ground photographs, as well as construction plans, were used in the investigation. Two interchanges were chosen for more detailed investigation. They were unique in that they both involved a left exit. The interchange of northbound I-287 with US-22

Sponsored by Committee on Motorist Information Systems.

was chosen because its geometric design was more conventional. At this site the drivers exiting to westbound US-22 are provided with 2 added, extra-long, high-speed deceleration lanes.

Interstate 287 is a particularly important location for study. When it is completed, it will connect with an Interstate system encircling New York City as I-495 encircles Washington, D. C.

STUDY SITE LOCATION AND DESCRIPTION

The chosen site is located in Bridgewater Township, Somerset County, approximately 10 miles northwest of New Brunswick. There are 4 interchanges in the 4 miles that precede the study site, the last of which is less than ½ mile away. On the northbound roadway, 3 lanes continue through. One lane is added on the right for the eastbound exit. Two lanes are added on the left for the westbound exit. These and other study site characteristics are shown in Figure 1. The approach to the first overhead sign (sign 2) is on a 1½-deg right curve. From that point to the last sign (sign 5), the road is tangent with a 2½ percent positive grade. The road then curves to the left on a 1½-deg curve beyond the last sign and maintains a slight positive grade.

PROCEDURE

Study and Sign Revision Sequence

The signs for the interchange of northbound I-287 at US-22 were altered or changed on 3 separate occasions (Figs. 2, 3, 4, and 5). The changes were made as follows:

1. Modification to a more standard form that was both in conformance with the Interstate sign manual (2) and compatible with the diagrammatic sign plans,
2. Replacement with new diagrammatic signs, and
3. Addition of lane lines within the diagrams.

The timing of sign changes and before-and-after studies was a major consideration in planning. The span of time between studies should not be so long that the proportion of unfamiliar drivers would be likely to change because of unknown causes. The span of time should not be so short between the sign change and the after study that familiar drivers would not have an adequate chance to get used to the new signs. It was decided that at least a week should be planned between the change and the after study, and no more than 2 months should be allowed between the before and the after studies.

Five separate studies were made of the sign changes. All the conditions of signing were studied, and each was compared with the previous condition. Studies were made in the following sequence, as shown in Figure 6.

1. Original signs versus modified signs—The original signs were studied in July and August 1969; the signs were modified in September and then studied in October. The comparison made was not a main objective but was included for informational purposes.
2. Modified signs versus diagrammatic signs—Diagrammatic signs were installed in late October 1969, and the data taken of modified signs in early October were compared with data from a study of diagrammatic signs made in November.
3. Diagrammatic signs in 2 seasons—Diagrammatic signs were studied in early May 1970 and in November 1969. The data were compared to measure the difference in the rate of unusual maneuvers with no changes in signing.
4. Diagrammatic signs versus diagrammatic signs with lane lines—Lane lines were added to the diagrams in late May 1970. The data from a study made in late June were compared with the data taken in May.

Study Procedure

In all studies, the number of unusual maneuvers at the exit gore from northbound I-287 to westbound US-22 were counted. The behavior of the traffic at the exit to eastbound US-22 was not studied because the volume of traffic using the eastbound exit was too small.

Figure 1. Study site.

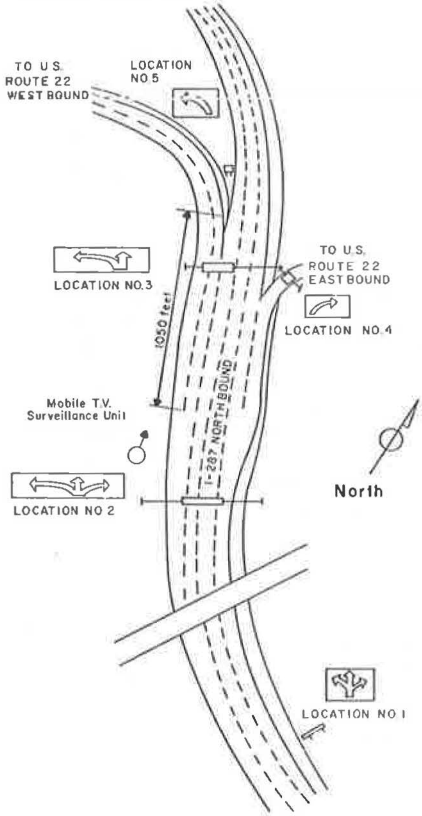


Figure 2. Sign 1.

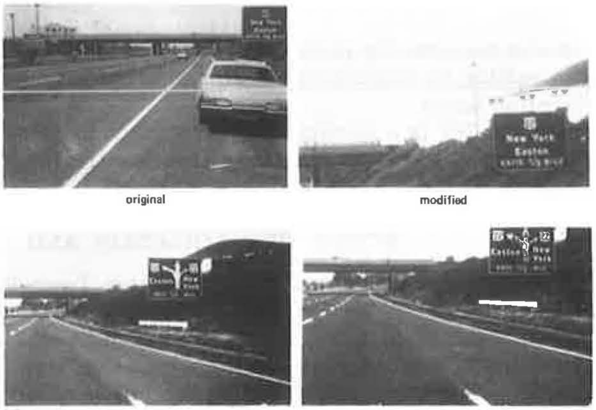
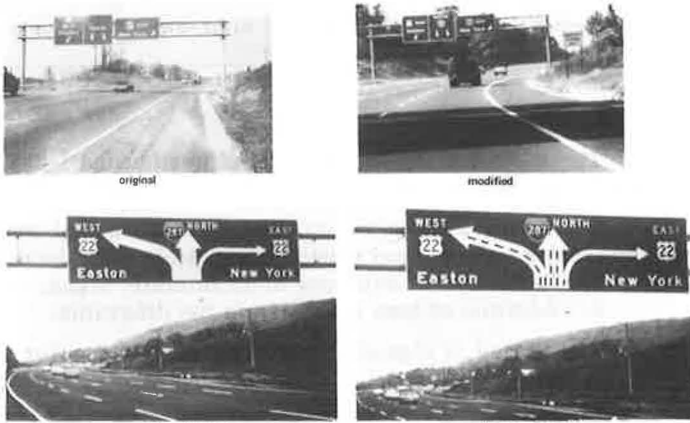

original
modified
diagrammatic
diagrammatic with lanes

Figure 3. Sign 2.



original
modified
diagrammatic
diagrammatic with la

Figure 4. Signs 3 and 4.

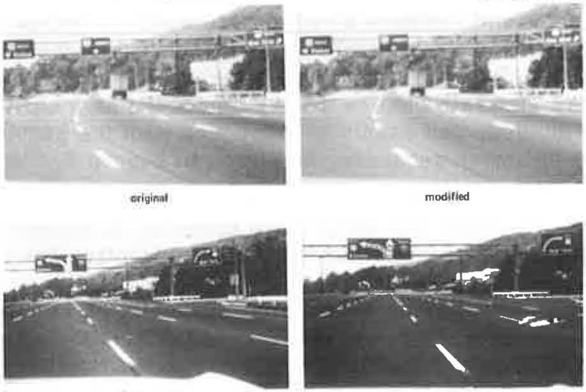
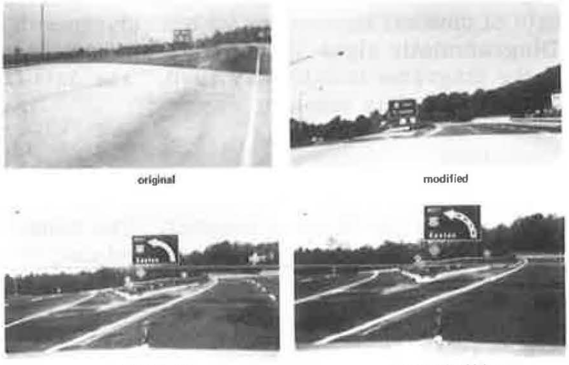

original
modified
diagrammatic
diagrammatic with lanes

Figure 5. Sign 5.


original
modified
diagrammatic
diagrammatic with lanes

Automatic traffic counters and TV recorders were used to record the data. Streeter-Amet hourly counters were placed to record the through volume and the left exit volume. The counters were placed at considerable distances past the exit gore so that they were not readily noticed by approaching drivers. The traffic approaching the exit gore was recorded on video tapes by means of a mobile TV surveillance unit (Fig. 7). The camera was adjusted to record all lanes from 400 ft upstream of the physical gore to the points beyond it. An audio band on the tapes recorded the time as announced every 5 min. Separate tapes recorded each hour of traffic. The study was limited to afternoon traffic.

The tapes were played back in the office under well-supervised conditions. A 15-min count of vehicles by number of axles was made for each hour. All unusual maneuvers that took place were noted and counted by hour (2 to 3 p.m., 3 to 4 p.m., and so on), movement (exit or through), number of axles (2 or more than 2), and initial and final lanes used. A summary of the unusual maneuver rates for 1 day (Monday) is given in Table 1.

Unusual Maneuvers Defined

An unusual maneuver, as defined for this study, includes any stopping, backing, or crossing the gore line in the section of northbound I-287 between the physical gore and a point 200 ft upstream of it (Fig. 8). The gore line in this case includes both the solid striped gore that is placed in front of the physical gore and the dashed line that continues upstream from the solid stripe. No more than 1 unusual maneuver was counted for any 1 vehicle. Some examples of unusual maneuvers are shown in Figure 8.

Data Correction

Several corrections to hourly data were necessary. Corrections for counter clock errors were made to the nearest 60th of a unit on a linear basis. Some missing through volumes were estimated on the basis of a linear regression analysis. The data for the regression were obtained from a study of volumes from prior weeks that were equivalent in day of week and time of day. The equation, $V = C/(X + 1.56y)$, was used to estimate the number of vehicles, given the machine counts, C, and the sample proportions of 2-axle, X, and 3- or more axle, y, vehicles in each hour. The constant 1.56 is based on a study of axle distributions made from earlier TV recordings from the same location. In cases where the television apparatus failed to yield a recording for short periods of time, the periods of failure were totaled for a given hour, and a linear correction was made to the unusual maneuver frequency totals.

Data Analysis

Comparisons were made by hour of exit. Two-axle rates were the only ones made because these categories consistently represented the vast majority of unusual maneuvers that occurred at the gore.

The Wilcoxon matched-pairs, signed-ranks method was used to test the significance of differences found in the comparisons (1, p. 361). The pairs were matched by hour, day, and number of axles. The following formula was used:

$$Z = \{T - [N(N + 1)]/4\}/\sqrt{[N(N + 1)\,(2N + 1)]/24}$$

where

T = smallest sum of ranks having similar signs;
N = number of qualified ranks; and
Z = normal standard deviation.

RESULTS

Original Signs Versus Modified Signs

No significant difference in the rates of unusual maneuvers was found at the 95 percent level of confidence after the signs were modified.

Figure 6. Time sequence of studies.

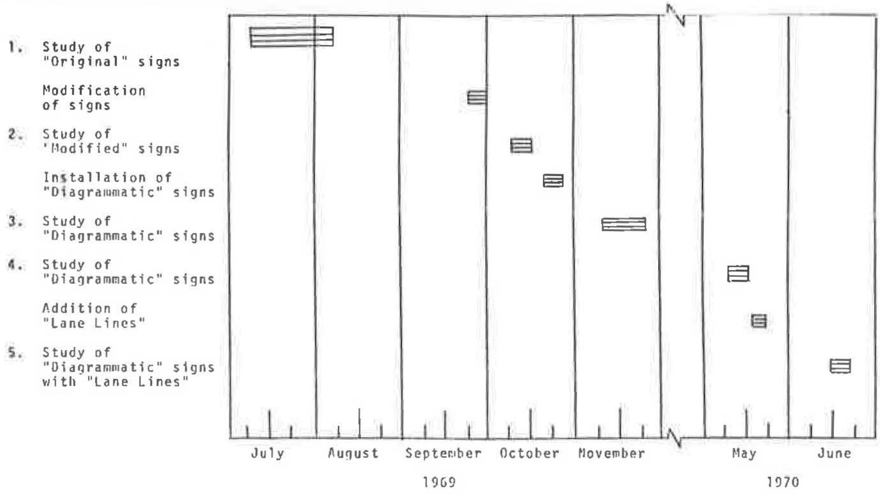


Table 1. Summary of unusual maneuvers on Mondays of 5 time periods.

				Lanes Used in Unusual Maneuver[a]											
				E				T		Total[b]		Volume		Rate	
Sign	Date	Hour (p.m.)	Axles	3-2	4-2	5-2	2-2	2-3	3-3	E	T	E	T[c]	E	T
Original	7-7-69	2-3	2	11	2			1		13	1	395		0.033	
			3+	0	0			0		0	1	25		0.000	
		3-4	2	11	1					12	0	476		0.025	
			3+	2	0					2	0	25		0.080	
		4-5	2	10	2	2		1		14	2	662		0.021	
			3+	0	0	0		0		0	0	50		0.000	
		5-6	2	16	1			2	1	17	3	772		0.022	
			3+	2	0			0	0	2	0	16		0.125	
		6-7	2	5	1				1	6	1	452		0.013	
			3+	1	1				0	2	0	56		0.036	
Modified	10-13-69	2-3	2	11		1		1		12	1	390	256	0.031	0.0
			3+	2		0		0		2	0	34	132	0.059	0.0
		3-4	2	12			1	1		13	1	555	343	0.023	0.0
			3+	1			0	0		1	0	48	86	0.021	0.0
		4-5	2	27	2			1		29	1	713	578	0.041	0.0
			3+	1	0			0		1	0	54	86	0.019	0.0
		5-6	2	16						16	0	725	657	0.022	0.0
			3+	0						0	0	15	42	0.000	0.0
Diagrammatic	11-24-69	2-3	2	15						15	0	383	297	0.039	0.0
			3+	1						1	0	20	147	0.050	0.0
		3-4	2	12	2			1		14	1	482	325	0.029	0.0
			3+	2	0			0		2	0	85	168	0.024	0.0
		4-5	2	10.3						10.3	0	605	584	0.017	0.0
			3+	1.7						1.7	0	115	174	0.015	0.0
Diagrammatic	5-11-70	2-3	2	15	1					16		274	207	0.058	0.0
			3+	5						5		87	111	0.057	0.0
		3-4	2	25				1		25	1	373	230	0.067	0.0
			3+	7						7		111	76	0.063	
		4-5	2	36	2			1		38	1	464	460	0.082	0.0
			3+	1						1		52	108	0.019	
Diagrammatic with lines	6-29-70	2-3	2	17	1			3		18	3	317	214	0.057	0.0
			3+	2	1			0		3	0	56	83	0.054	0.0
		3-4	2	13	0			5		13	5	396	236	0.033	0.0
			3+	5	1			0		6	0	75	117	0.080	0.0
		4-5	2	32	1			1		33	1	626	319	0.053	0.0
			3+	3	0			1		3	1	62	90	0.048	0.0

Note: E = exiting vehicles, and T = through vehicles.

[a] See Figure 8. [b] May reflect miscellaneous categories not shown. [c] Not available for July 7, 1969.

Figure 7. Mobile TV surveillance unit.

Figure 8. Identification of unusual maneuvers.

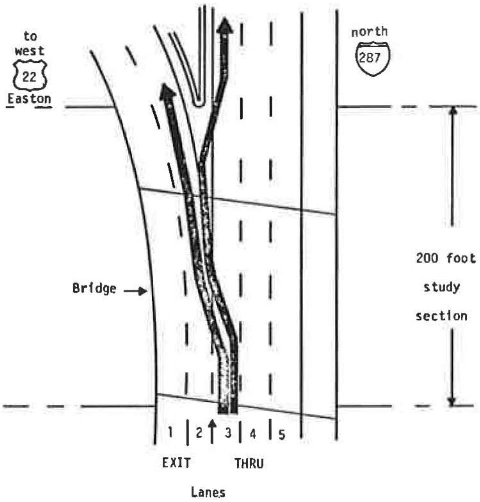
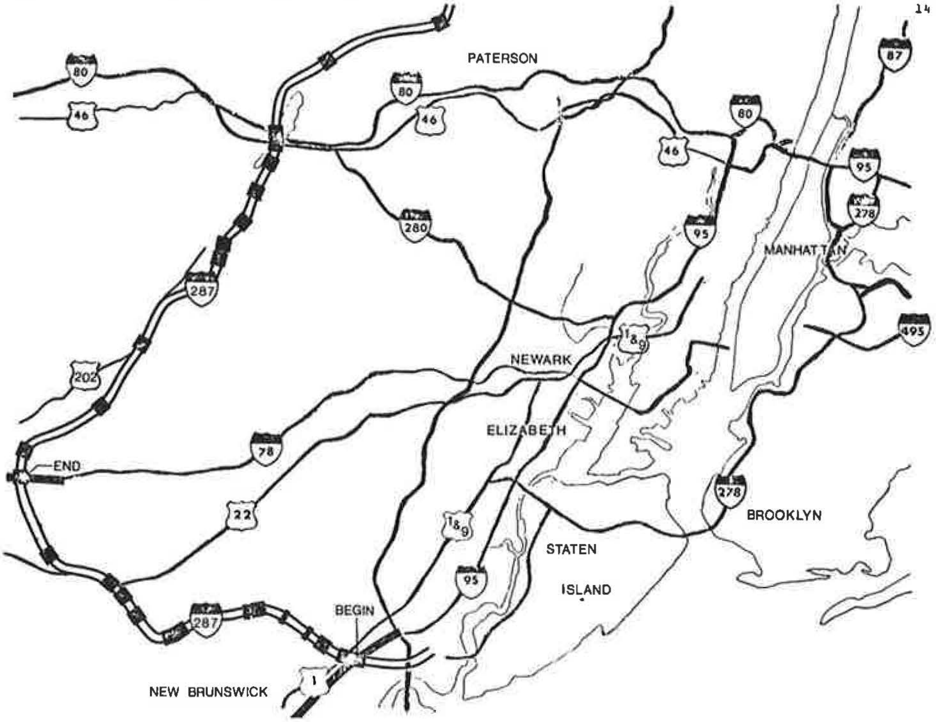


Figure 9. Area of proposed sign changes.



A significantly lower rate could have been expected with the modified signs if it can be accepted that October will have a lower proportion of unfamiliar motorists than July or August.

Modified Signs Versus Diagrammatic Signs

A significant reduction at the 95 percent level of confidence in the rates of unusual maneuvers was found after diagrammatic signs were installed.

The specific changes made on the signs were (a) the exchange of diagrammatic with conventional arrows and subsequent repositioning of messages and (b) the addition of one US-22 shield on the first sign.

The reduction in the rates may be partially attributed to these changes, but they may also be partially attributed to (a) the greater attention value from the uniqueness of the signs within the I-287 system and (b) the motorist's feeling that greater importance has been put on his needs at this particular location.

Diagrammatic Signs in Two Seasons

A significant increase at the 95 percent level of confidence was found in the rates of unusual maneuvers after no changes were made to the diagrammatic signs.

The higher rate may be partially attributed to the fact that the 2 sets of data compared were collected in unlike seasons and partially attributed to effects on the comparison brought about by other causes allowed to operate during the relatively long span of time (6 months) between collection periods.

Diagrammatic Signs Versus Diagrammatic Signs With Lane Lines

A significant reduction at the 95 percent level of confidence in the rates of unusual maneuvers was found after lane lines were added to the diagrammatic signs.

A higher rate could have been expected, assuming that June has a higher proportion of unfamiliar drivers than May.

DISCUSSION AND OBSERVATIONS

Observation of the diagrammatic signs points out some apparent improvements over standard signing.

1. The exit directions are more clearly communicated at more advanced locations as well as at the most advanced location, which is at the first sign.
2. The number of lanes for a movement can be communicated at the most advanced point. This may be done by a display of different arrow stem thicknesses and lane lines.
3. The destination and route number information is more meaningful because it is matched with the major diagrammatic components of the interchange on all signs. The motorist does not, therefore, have to infer the match in advance because this is done for him.
4. The driver's position relative to the exits within the interchange is more adequately communicated. Arrow stem connections and lengths show the choices left to the motorist at the sign locations.
5. The attention value of the diagrammatic signs in this study seems greater than that of the conventional signs, perhaps because the arrows add more white area.

Although a statistically significant reduction in the rate of unusual maneuvers was found after the diagrammatic signs were installed, an "ideal" application had not been made. Because of the restriction on the study that the present structures be used, the following observations were made.

1. The sign at location 3 was not referenced on the lane line that divides exit from through movements. A more ideal placement—8 ft to the left and at a more advanced point—was not possible because of the overhead structure's wind-load capacity and its constructed position.
2. In the mind of the motorist, the possibility that the exit ramp referred to on the sign at location 5 may be farther down the highway is not entirely eliminated. The sign

may have been better placed over the exit ramp on a cantilever structure with its support on the outside of the ramp.

RECOMMENDATIONS

It is recommended that further evaluation of diagrammatic signing under basic conditions be carried out for cloverleaf geometry, diamond geometry, and an entire series of interchanges. Serious consideration should be made that new standards include the diagrammatic concept.

Additional studies at US-22 should be made to learn more about the variable of unusual maneuvers as a sign-value parameter and the factors that affect it.

FUTURE PLANS

The Bureau of Operations Research has proposed a more extensive study. The proposal includes the replacing of all the signs on I-287 from the New Jersey Turnpike through the interchange at I-78 (Fig. 9). The proposed studies of 10 ramps within this section would add more data on the diagrammatic concept and also answer the question of "uniqueness" of these signs within a standard system because all the interchanges would have diagrammatic signs. This means that by the time the unfamiliar northbound driver would arrive at US-22 and other interchanges, the novelty of seeing diagrammatic signs would have worn off.

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EVALUATION OF DIAGRAMMATIC SIGNING AT CAPITAL BELTWAY EXIT 1

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A conventional sign on the westbound approach to exit 1 of the Capital Beltway was replaced by a diagrammatic sign to determine the effect of the new sign on driver behavior. Before and after phases of the study evaluated the effects of the sign in terms of erratic maneuvers, which were classified into the following types: weaving (across solid line and gore area), hesitating, stopping-backing, and partial weaving. The analysis of each maneuver within designated zones throughout the interchange revealed the numbers of maneuvers at critical points. After the diagrammatic sign was installed, weaving maneuvers in the gore area decreased; partial weaves increased, but vehicle hesitations and stopping or backing were fewer; and accidents were reduced 35 percent during 11 months.

•METHODS to eliminate motorist confusion at high-speed interchanges are needed on high-volume Interstate highway sections. The signing of these roads poses particular problems because of the close interchange spacing, the multiplicity of exits, and the large number of intersecting arterials. At present, so much confusion exists at numerous Interstate highway interchanges throughout all states that research is needed to establish criteria for evaluating signing at these locations.

A 2-year project undertaken by the Virginia Highway Research Council will examine some major urban Interstate highway interchanges throughout the state. Data will be taken at all interchanges, and driver behavior will be examined for the possible determination of the effects of variables such as geometrics, interchange type, and signing. This report presents the results of a pilot study of one intersection undertaken to assist in the design of the long-range project.

PURPOSE AND SCOPE

This experiment was undertaken to analyze the effect on motorists of a single diagrammatic sign and to determine procedures for a statewide testing program. Erratic maneuvers were classified for use in evaluating driver confusion in future studies. Certain diagrammatic signing principles were established that will provide guidelines for the long-range study. Because of manpower and time constraints, the scope of the study was limited to one problem interchange for flow in one direction.

METHOD OF APPROACH

The "comparative erratic maneuver" technique consists of observing, recording, and analyzing arbitrarily defined erratic movements to compare driver behavior for various signing schemes. The study area was divided into several zones, and data were collected for each zone. A review of accident data covering a 2½-year period prior to the study was used to designate accident-prone points within the study area and to help establish the study zones. Thus, one objective of the study became the examination of erratic maneuvers at the most accident-prone points of the interchange.

The variables included in the analysis were erratic maneuvers, type and location of maneuver, traffic volumes, time of day, and a variation in signing. Data were collected by manual recording and by time-lapse photographic equipment. A description of the study procedure is found in a later section of the paper.

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The analysis describes the effect of diagrammatic signing on erratic-driver movements at critical points in the interchange. From this analysis and related study, generalizations may be drawn to establish criteria for relatively confusion-free signing for high-speed interchanges.

STUDY LOCATION

Observation at exit 1 of the Capital Beltway just south of Alexandria, Virginia, has shown it to be a problem interchange that can be analyzed in terms of numerous parameters. Studies of the interchange by both the author and members of the Virginia Department of Highways have described the problem in terms of geometrics, speed data, accident data, and capacity characteristics.

Geometrics

Figure 1 shows a schematic of exit 1 as approached by westbound traffic. Unusual geometrics are characterized by the fact that the driver is confronted by a lane drop and then by 3 exit ramps leading from a collector-distributor road. The sight distance to the approach is severely limited by a bridge abutment, as shown in Figure 2.

Speed Data

Based on the results of a speed study conducted by the Traffic and Safety Division of the Virginia Department of Highways, the 85th percentile speed on the approach during the morning and evening peak hours is about 45 mph. This relatively low speed is due to the heavy traffic volume and weaving conditions that exist at those times. During off-peak hours, the 85th percentile speed increases to around 65 mph.

The Traffic and Safety Division examined warrants to explore the possibility of changing speed limits. It was concluded that no applicable warrant exited and that new speed limits would be difficult to enforce and would have a questionable effect on the accident rate.

Accident Data

During the period from January 1, 1968, through March 31, 1970, there were 240 accidents in which 4 persons were killed and 136 injured; measurable property damage was more than $184,000. Figure 3 shows a collision diagram for the vicinity of the first gore, in which there were 38 accidents, 1 fatality, 25 injuries, and property damage amounting to approximately $28,000.

Accident statistics reveal some very interesting facts, but the conclusions regarding causes must be largely subjective. Of primary concern in this study is the large number of sideswipe and rear-end collisions at the first gore area approaching the exit. These accidents appear to be the result of driver confusion caused by a lack of advance notice of the lane drop. Based on this supposition, this paper places major emphasis on erratic maneuvers at that location.

Capacity Characteristics

Volume counts taken in 1970 indicate that there are some 81,000 vehicles passing the intersection every day. Unfortunately, ramp volume counts for the exits are not available.

A study was made to examine the existing volume-to-capacity relations. Freeway capacity charts were used to determined that the design capacity of the upstream approach (the Woodrow Wilson Bridge) was approximately 2,600 vehicles/hour in the westbound direction. The design capacity in this instance was based on level of service A, i.e., a speed of approximately 65 mph and freedom of driver movement. The maximum capacity is reached at level of service E and is approximately 5,000 vehicles/hour. Peak-hour volumes exceeding 4,700 vehicles/hour were recorded during the study, and that fact explains the speed reduction to around 45 mph during peak periods.

Figure 1. Capital Beltway westbound at exit 1 just south of Alexandria.

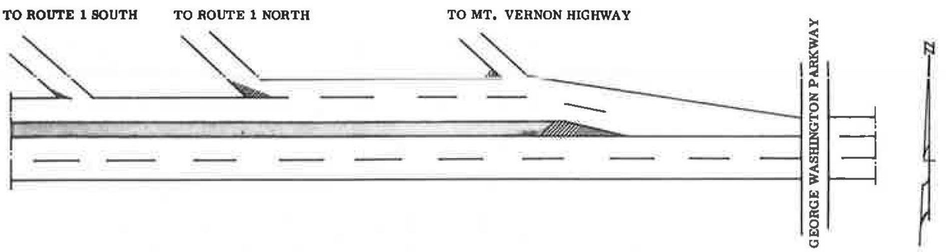
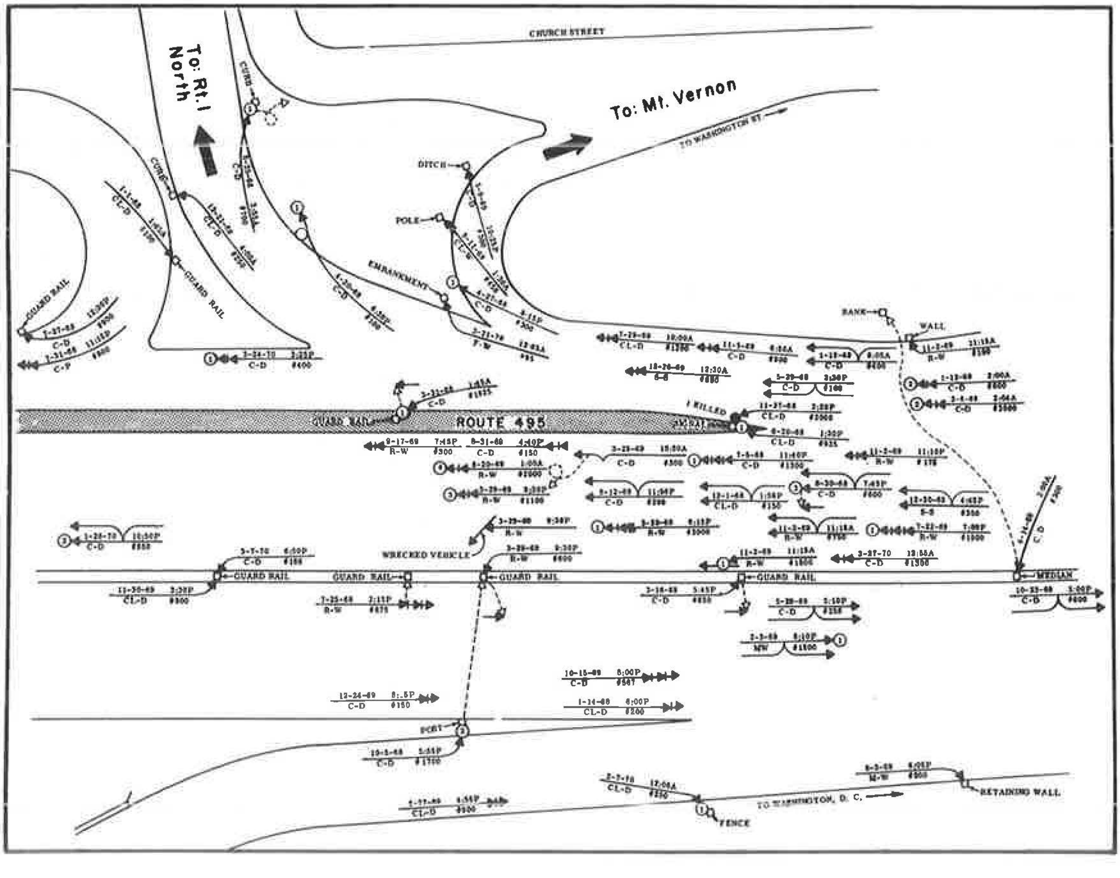


Figure 2. Limited sight distance on the approach to exit 1.

Figure 3. Accidents occurring at exit 1 westbound from January 1, 1968, to March 31, 1970.



From the analysis given above, it would appear that much of the problem at exit 1 can be attributed to the high volume-to-capacity ratio. However, only about 20 percent of the accidents occur during peak hours, which fact warrants a study of signing effectiveness with respect to relating the unusual geometric conditions to the motorists' actions.

PROCEDURE

The effects of diagrammatic signing on driver behavior were determined by the use of the "comparative erratic maneuver" method of analysis. The study area was divided into zones as shown in Figure 4, and erratic vehicle movements were recorded for each zone. A time-lapse camera was focused on zone 3, for this was thought to be the most critical zone because of the short weaving section located within it. Data for zones 1 and 2 were collected manually by observers stationed on the Washington Street Bridge in the positions shown in Figure 4. The designation of erratic maneuvers used in this study was as follows:

Maneuver	Type
Weaves (as shown in Fig. 4)	1
Weaves (over gore areas)	1a
Hesitations (slow to approximately 15 mph)	2
Stopping or backing or both	3
Partial weaves	4

Volume and erratic maneuver data were recorded at random times throughout the day for half-hour intervals. Observations started as early as 7:00 a. m. and ended as late as 5:00 p. m. Data for the "before" traffic characteristics were collected during the late fall and early spring. On March 29, 1971, the conventional sign on the approach to exit 1 was replaced by a diagrammatic sign. Observations were then undertaken to evaluate the traffic characteristics resulting from the change in signing. Figure 5 shows both the conventional sign and the new diagrammatic sign.

The standard for the diagrammatic sign is similar to those recommended by Serendipity, Inc. (1), and utilizes 20-in. route-name lettering and 36-in. shields to comply with AASHO standards for Interstate highway signing. The 14- by 19½-ft size is the maximum allowable on the existing overhead structure.

The variables measured directly were erratic maneuvers, traffic volume, and time of day. Because of a manpower shortage and high traffic volumes, it was impossible to record all license plate designations or otherwise to directly measure the effect of seasonal traffic variations. The effect of seasonal traffic was evidenced by an overall increase both in volume, as shown in Figure 6, and in total weaves. However, its significance as a variable can be considered nonexistent based on findings of the statistical tests, which are described in a following section.

ANALYSIS

The analysis was based on observations of traffic at exit 1 during a period of 19 days. In this period, 56,326 vehicles were observed during 47 half-hour intervals before the installation of the new sign, and 91,423 vehicles were observed during 73 half-hour intervals after the installation. An average of 9.03 percent of all vehicles passing the interchange made erratic maneuvers, thereby affording an adequate sample size for analyzing the behavioral patterns of motorists.

The traffic characteristics of the before and the after conditions were compared in terms of different patterns of erratic maneuvers. The erratic maneuvers observed as statistically comparable variables are given in Table 1. The relation of the variable, the observed mean for the before and the after conditions, the statistical tests, and their significance are given in this table.

Data given in Table 1 lead to the conclusion that, although the tourist traffic did not significantly increase the mean traffic volume, it did increase the total weave-to-volume

Figure 4. Exit 1 zone and weave designations.

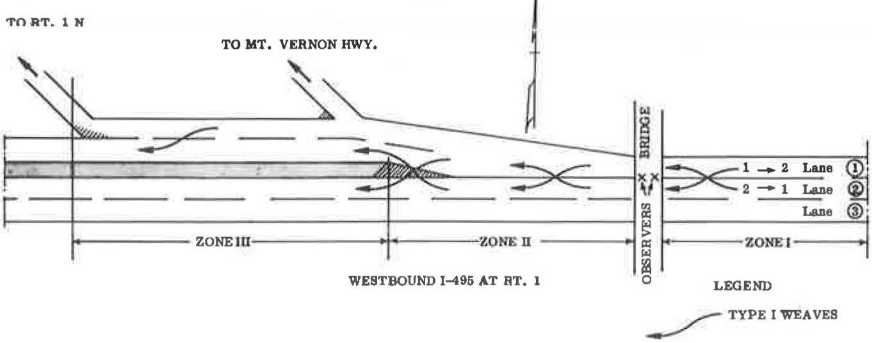


Figure 5. Conventional and diagrammatic signs at exit 1.

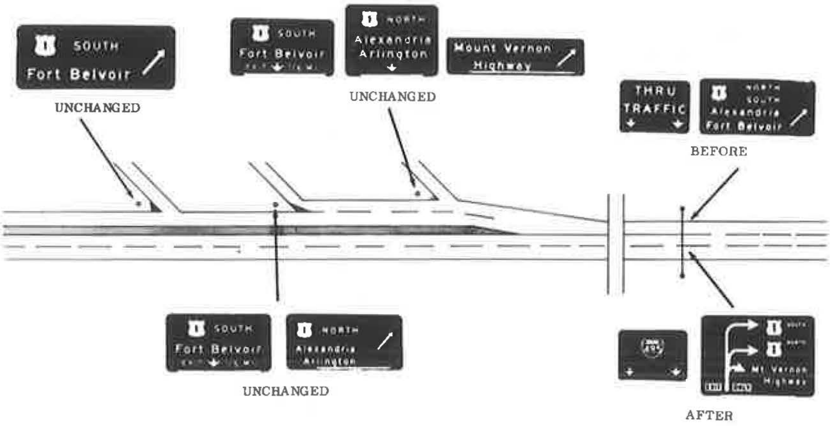


Figure 6. Seasonal traffic trend.

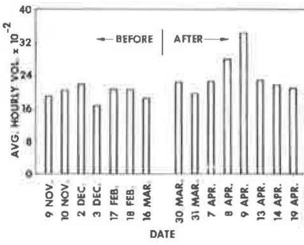


Table 1. Statistical comparison of variables—study period data.

Variable	Mean		Significance Test		Population Change
	Before	After	t	F	
Volume, vehicles/½ hour	1,198.38	1,298.87	1.06	1.13	Not significant
Weaves/volume, × 10^2					
Total, all traffic	8.22	9.84	3.08[a]	1.36	Higher
Total, rush-hour traffic	9.90	7.52	2.17[a]	2.20[a]	Lower, less variable
Gore, all traffic	81.60	69.20	1.63	2.56	Not significant
Gore, rush-hour traffic	98.20	65.50	4.53[a]	2.43[a]	Lower, less variable
Zone 1, all traffic	59.01	67.63	1.91	1.55	Not significant
Zone 2, all traffic	9.48	12.92	4.46[a]	1.04	Higher
Zone 3, all traffic	15.14	18.17	2.38[a]	1.30	Higher
1-2, all traffic	30.37	40.33	3.34[a]	1.87	Higher
Weaves/total weaves, × 10^2					
Gore, all traffic	10.03	6.77	4.84[a]	2.29[a]	Lower, less variable
Gore, rush-hour traffic	9.85	7.08	3.73[a]	2.47[a]	Lower, less variable
Zone 1, all traffic	69.53	68.79	0.36	2.44[a]	Less variable
Zone 2, all traffic	12.52	13.58	2.05[a]	1.63	Higher
Zone 3, all traffic	17.93	17.61	0.18	1.25	Not significant
1-2, all traffic	35.00	37.15	1.16	1.89	Not significant

[a] Significant value. $\alpha = 0.05$.

ratio. However, the data show that fewer motorists (per unit volume) did weave across the gore. This, in itself, attests to the fact that a safer condition existed at the interchange after the new sign was installed despite the influx of tourist traffic. The increased seasonal traffic was due to the spring tourist attractions in the Washington, D. C., area. It should be emphasized that a significant reduction of erratic movements in the gore area indicates a reduction of driver confusion in this critical area.

A regression analysis of weave-to-volume ratio versus volumes further illustrated the change in traffic behavior between the before and the after conditions. Figure 7 shows the regression analyses; both the points and a linear fit are shown. Although the coefficients of correlation are relatively low (approximately 0.75), the analyses are not without significance.

A comparison of gore weave-to-volume ratios and volume regression analysis plots shown in Figure 8 for the before and the after conditions indicates that a safer condition existed when the traffic volume was under 3,400 vehicles per hour. The average observed non-rush-hour volumes for seasonal and off-seasonal conditions, also shown in the figure, indicate that the safer conditions existed most of the time.

It is highly doubtful that the upper volume range actually does exhibit a higher percentage of gore weaves as data shown in the figure would imply. The line for the after condition is deceptively high because of increased weaving of tourist traffic and the fact that most of the data points reflect the low-volume condition. Furthermore, observations of high-volume (rush-hour) conditions during this study and prior research on the Beltway by Shepard (2) show weave-to-volume ratios to be much lower during these times. The gore weave-to-volume ratios during rush periods for this study were as follows:

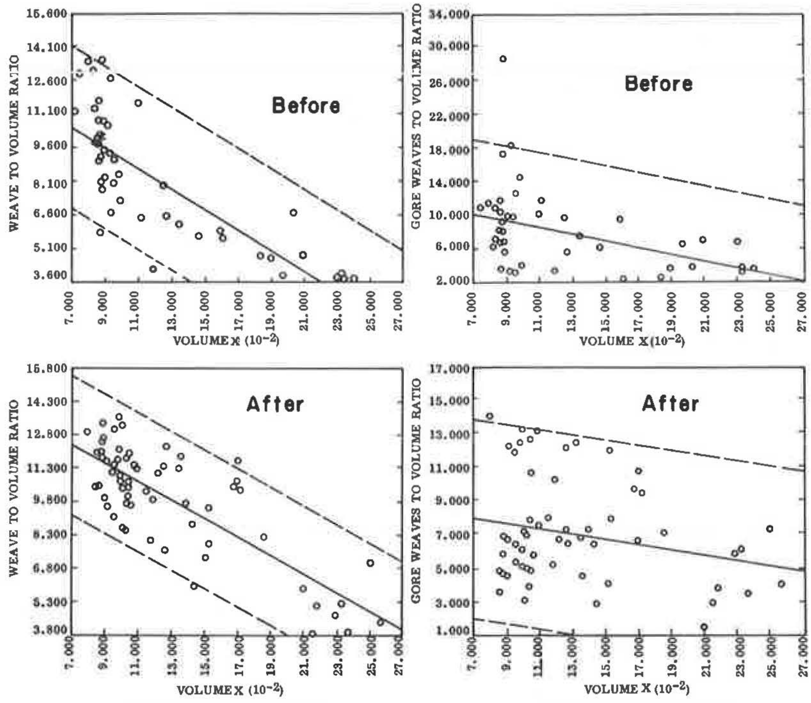
Time	Before	After
a. m.	3.37	2.79
	3.70	1.43
	3.45	3.66
	2.74	3.38
p. m.	6.61	5.68
	6.95	7.19
	6.71	6.02
Avg	5.08	4.66

The effect of the sign change on weaving by zone is also given in Table 1. The weaving in each zone is expressed both as a fraction of the total volume and as a percentage of the total weaves. Although the overall percentage of vehicles weaving was higher because of the tourist traffic, a slight decrease in the percentage of weaves in zone 1 indicates that the new sign offered the needed advance warning for the interchange. The total weave-to-volume ratio showed an increase of 1.62 percent for the entire interchange during the after study period, yet the zone 1 weave-to-total weave ratio decreased by 0.38 percent indicating that many motorists did weave before entering the study area. Increased erratic maneuvers in zones 2 and 3 were generally consistent with the increase in volumes due to the increase in tourist traffic.

The total number of vehicles weaving across the solid line pavement marking into the mainstream of traffic increased significantly during the after period. This maneuver, designated as a 1-2 weave, increased about 33 percent per unit traffic volume yet increased only 2.15 percent with the total observed erratic maneuvers. This further indicates that tourists benefited from the advance warning provided by the new sign and that a relatively high percentage of nonexiting tourist traffic did weave in advance of the interchange. Inference is thereby made that, were the new sign not in place, many tourists would not have weaved until reaching the gore area, thereby creating an additional hazard.

Table 2 gives a summary of erratic maneuvers by type and by zone. For the purpose of the analysis by type, the weaves over the gore area were included with the type 1 weaves. The earlier separate treatment of gore weaves showed a significant reduction in the after study.

Figure 7. Regression analyses results.



TOTAL WEAVES VS. VOLUME

GORE WEAVES VS. VOLUME

Figure 8. Gore weaves and volume.

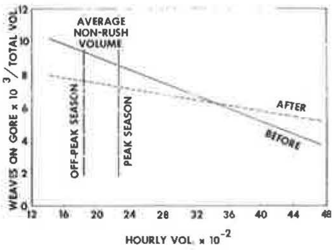


Table 2. Erratic maneuvers by type and zone.

Type	Zone	Number Before	Number After	Avg per Vehicle ($\times 10^{-3}$) Before	Avg per Vehicle ($\times 10^{-3}$) After	Change (percent)
1	1	2,881	5,741	51.15	62.79	+22.8
	2	476	1,038	8.45	11.35	+34.3
	3	541	732	9.61	8.01	-16.6
Total		3,898	7,511	69.21	82.16	+18.7
2	2	10	48	0.18	0.53	+194.4
	3	3	14	0.05	0.15	+200.0
Total		13	62	0.23	0.68	+195.7
3	2	24	28	0.43	0.31	-27.9
	3	21	29	0.37	0.32	-13.5
Total		45	57	0.80	0.62	-22.5
4	2	9	20	0.16	0.22	+37.5
	3	178	695	3.16	7.60	+190.5
Total		187	715	3.32	7.82	+135.5
Total maneuvers		4,143	8,345	71.55	91.28	+27.6
Total volume		56,324	91,423			+38.4

Table 3. Comparison of variables—March data.

Variable	Mean Before	Mean After	Significance
Avg volume, vehicles/½ hour	1,198.38	1,257.42	—
Weaves/volume, $\times 10^2$			
Total, all traffic	8.94	8.71	—
Gore, all traffic	107.00	49.70	t, F
Gore, rush-hour traffic	126.00	56.00	t, F
Weaves/total weaves, $\times 10^2$			
Gore, all traffic	11.66	6.11	t
Gore, rush-hour traffic	12.03	5.66	t

The average erratic maneuver per vehicle increased more than 27 percent in the after phase, largely because of the increased weaving by tourists. A substantial increase was seen in the number of vehicles that slowed down in zones 2 and 3 and that made partial weaves in zones 3; however, a favorable trade-off is evidenced by a 22.5 percent reduction in the number of vehicles that stopped or backed. It is also noteworthy that type 1 weaving was reduced by 16.6 percent in the critical zone 3.

The increased hesitations and partial weaving may be attributed in part to initial driver confusion on seeing the unfamilar diagrammatic sign. Despite the higher percentage of erratic maneuvers in the after phase, the trade-off among types of behavior would probably be indicative of a safer condition. The stopping-backing erratic maneuver that was reduced can be seen to be more dangerous than the partial weaving and hesitating types, which were increased. The driver has more control over his vehicle during the weaving and hesitating than during the stopping-backing maneuvers. However, because the magnitude of increased erratic maneuvers exceeded that of the reduced, a conclusion that the trade-off yielded a safer condition would be somewhat speculative.

To isolate the effect of seasonal traffic, a partial analysis was made of data collected during the month of March. Included in this limited sample were observations made during the 2 days of data collection before installation of the sign and during the 2 days immediately after installation. Table 3 gives the results of the analysis, which denote the immediate reduction of weaves over the gore area.

Unlike the results for the entire study period, those here show a slight reduction in the total weave-to-volume ratio. This reduction follows by virtue of the nulled seasonal effect of increased weaving by tourists combined with the confusion-reducing effect of the sign. Significant reductions in gore weaves compared both to volume and to total weaves are verified by statistical tests. The F-test used in analyzing the gore weave-to-volume ratios indicates that driver behavior was less variable following the sign installation. The reduction of gore weaves is seen to be most significant during the non-rush-hour periods of traffic. This is consistent with the fact that driver habits during peak-hour conditions at urban interchanges are less dependent on signs. More drivers are familiar with the interchange, for many of them are daily commuters.

As a further aid in determining the effect of the diagrammatic sign, driver opinions were sampled. Because of a manpower shortage, continuous driver interviews throughout the study were not possible. However, driver attitudes were sampled at random intervals by interviews with confused motorists who had stopped on the shoulder or who asked for directions at a nearby service station. In most cases, lost motorists were looking for Beltway exits other than exit 1. Prior trip planning and better use of road maps would have eliminated most of the reported driver-confusion problems. Motorists were shown pictures of the diagrammatic sign, and their general response indicated that the sign, although initially confusing, contained much helpful information. The only conclusion drawn from the driver interviews was that much of the current driver confusion at exit 1 is due to poor orientation to the area.

A valid comparison of accident data between the before and the after conditions is not possible because insufficient time has elapsed since erection of the diagrammatic sign to develop an after-period accident history. However, it is noteworthy that accident data before the installation of the diagrammatic sign revealed an accident rate of more than 1 per month on the approach. For the 11 months following the installation, there has been a 35 percent reduction in accidents.

An overview of the analysis shows an attempt to contrast motorist behavioral patterns between the before and the after conditions in terms of erratic maneuvers. A statistical analysis of erratic maneuvers as a function of total volume has revealed a higher percentage of weaves after installation of the diagrammatic sign. However, the increased weave-to-volume ratios can be attributed primarily to seasonal traffic differences as evidenced in the analysis of the March data.

CONCLUSIONS

The combined effects of general acceptance by motorists evidenced through improved advance warning and of initial confusion of motorists due to lack of familiarity with diagrammatic signing were reflected in this study. An influx of seasonal traffic due to spring tourist attractions in the Washington, D.C., area was also partially responsible for an increased percentage of erratic maneuvers after the installation of the sign. Nevertheless, significant results in terms of erratic driver behavior could be seen through comparison of the before and the after studies.

Specific conclusions that may be derived from this study are as follows:

1. A significant reduction of weaves over the gore area indicates a safer interchange as a result of improved advance warning provided by the diagrammatic sign;
2. A lesser increase of zone 1 maneuvers relative to total maneuvers implies that much traffic did weave before entering the study area, and a reduction of zone 3 weaves indicates that drivers did benefit from the geometric information provided by the sign;
3. The effect of the sign on the type of maneuver is seen by a trade-off between increased hesitations and partial weaves coupled with decreased stopping and backing movements, and this result is indicative of a safer interchange because hesitations and partial weaves are less dangerous than stopping and backing;
4. Informal driver interviews indicated that much of the problem at exit 1 stems from poor orientation to the area, yet motorists felt that diagrammatic signs convey much needed information and encouraged further research; and
5. Insufficient time has elapsed since erection of the sign for a valid statistical comparison of accident data, but in 11 months of sign usage the accident rate has been reduced by 35 percent.

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DRIVER INFORMATION SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

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The first objective of this research was to evaluate driver attitudes concerning hazards at highway-railway grade crossings. Respondents considered highway-railway grade crossings relatively more hazardous than other potential highway hazards but considered none of the potential hazards to be very serious. The second objective was to evaluate the economic priorities for improving railroad grade crossings relative to eight other highway improvements. Respondents considered safety at highway-railway grade crossings to be very important. The third objective was to evaluate driver preferences for information systems to be used at highway-railway grade crossings. An overhead changeable-message sign was the most preferred alternative method of warning. The fourth objective was to evaluate driver preferences for messages to be used in an information system for highway-railway grade crossings. The respondents preferred information even when no train was present and preferred full words rather than abbreviations.

• HIGHWAY-RAILWAY grade crossings constitute a hazard to the highway traveler. In the United States in 1969 there were 3,774 grade-crossing accidents involving pedestrians, automobiles, trucks, buses, motorcycles, and other miscellaneous vehicles (1). These grade-crossing accidents resulted in 1,490 fatalities and 3,669 personal injuries. Railroad grade crossings account for only 0.1 percent of the total accidents in the United States (2). However, these accidents are very severe. The severity is indicated by the fact that railroad crossings account for an average of 2.5 percent of the total automobile accident fatalities in the United States (2).

Of the 3,774 crossing accidents in 1969, 3,572 involved collisions between railway vehicles and highway vehicles. These 3,572 accidents resulted in 1,381 deaths and 3,578 injuries. In two-thirds of these 3,572 accidents, trains struck motor vehicles. The remaining one-third of these accidents involved motor vehicles that struck the sides of trains (1).

Protected crossings (those having gates, trainmen, watchmen, or audible or visual signals or both) account for approximately 22 percent of the 211,993 highway-railway grade crossings in the United States. Protected crossings, however, account for approximately 42 percent of the 3,572 motor vehicle accidents at grade crossings (1). Although other factors such as train and motor vehicle volumes are involved, it would appear that present protective devices are less effective than would be desirable.

The grade-crossing problem is even more serious in Indiana. In the period from 1965 to 1968, 0.4 percent (0.1 for the United States) of the total accidents and 6.0 percent (2.5 for the United States) of the total fatalities in Indiana occurred at railroad grade crossings (1). Indiana consistently has a large number of railroad-crossing accidents.

It is worthwhile to look at rural grade-crossing accidents. The higher operating speeds at rural crossings are reflected in accident severity. During the period from

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Sponsored by Committee on Highway-Railroad Grade Crossings.

1966 to 1968, rural Indiana railroad-crossing accidents averaged 31 percent of the total grade-crossing accidents. However, fatalities averaged 56 percent of the total fatalities (3). Thus, it would seem that rural grade-crossing accidents, at least in Indiana, are more severe than urban grade-crossing accidents.

It should also be noted that, although all grade crossings average 1 traffic accident every 22 years, some grade crossings have a number of accidents every year. For example, one crossing on US-52 in Indiana has had at least 1 fatality and 4 total accidents each of the past 3 years (3). These accidents occur despite automatic protection in the form of flashing lights. It becomes evident that present protection systems, short of complete grade separation, are at best only partially successful.

The focus in the past concerning railroad grade-crossing problems has been primarily on hazard-index formulas and accident-prediction equations. The purpose of these formulas and equations has been to determine the priorities for the improvement of protection at specific grade crossings. The reason that priorities are needed is that there are numerous grade crossings that could be improved, the cost of improvement such as flashing lights and gates is large, and the amount of money available is limited.

Indications are that current techniques for computing the relative hazard index are reliable. Bezkorvainy applied 11 hazard-index formulas to 180 railroad grade crossings and concluded that each formula gave basically the same relative priority for improvement of the crossings (4). In addition, Schultz has developed models to predict the relative hazard for rural grade crossings in Indiana, and Berg developed similar models for urban areas (5, 6).

Other significant research can be categorized as before-and-after studies. Voorhees concluded that the results of numerous before-and-after studies indicate general agreement concerning the relative effectiveness of present protection devices in reducing the hazard at a railroad grade crossing (2). Automatic gates are considered to be the most effective protection and are followed in order by flashing lights, wigwags, and crossbucks.

Although complete grade separation is one solution to reducing grade-crossing accidents, grade separations require substantial resources. There is a large cost differential between a grade separation and present automatic protection systems. Flashing lights with gates cost approximately $25,000 for installation. The cost of a grade separation ranges from $300,000 for a 2-lane rural location to more than $800,000 for a 4-lane urban location (2). Therefore, situations exist that could justify more effective protection at a cost less than that of a complete grade separation.

It would seem that future research efforts might be more appropriately directed toward improving safety measures at individual crossings, especially in rural areas. An area that has received little attention in the past is that of basic information supplied to the motorist at highway-railway grade crossings. The standard flashing lights are located adjacent to the roadway and tracks. Besides constituting a hazard because of their location, the lights may not adequately provide sufficient advance warning. Studies in human factors also indicate that the distinctive round shape of the present advance-warning sign cannot be discerned before the message (7).

New technology in electronics permits better information to be furnished to the driver. Signs that can display several different messages outside the vehicle are available, and it is possible to provide signals or messages that are audible or visual or both within the vehicle.

SOME PREVIOUS PERTINENT RESEARCH

As the task of driving has become more complex, interest has increased in driver-information systems. Basic static signs (i.e., signs that always display the same message) are not desirable in many driving situations. Some agencies have begun to use changeable-message signs. Examples include variable speed signs, warning signs for bad weather or accidents, and signs used to give freeway conditions or information on alternate routes. As the electronic capabilities continue to be developed and perfected, these signs should find increasing usage in many different situations. Review of previous research into driver-information systems utilizing advanced electronic capabilities has provided the basis of this research concerning an advance-warning system for railroad grade crossings.

Changeable-Message Signs

The Chicago Area Expressway Surveillance Project has conducted research on the provision of real-time information on the operation of the westbound Eisenhower Expressway and its entrance ramps (8). Electronic signs are operated in conjunction with expressway ramp control provided by the Chicago Area Expressway Surveillance Project. Electronic surveillance of the number and location of vehicles on the expressway is used to control the number of vehicles entering the expressway at each entrance ramp. In conjunction with the ramp metering, changeable electronic signs are used to alert drivers to the traffic conditions at the various ramps and merge areas. These signs, through color coding, help the driver to determine whether he should use the expressway or the arterial street system for his trip.

In-Car Devices for Driver Information

There have been experiments using radio transmissions to provide drivers with information on traffic conditions (9, 10, 11). The type of radio transmission most applicable to this research is based on the induction loop principle. This induction loop principle simply uses a buried cable near the roadway as a means of transmitting a radio signal over short distances. This short range results in a minimum of interference with regular radio stations. The induction loop broadcasts can be received on regular car radios or special receivers.

A radio communications system has been developed by General Motors (11). The system is called Driver Aid, Information and Routing (DAIR). This particular system has 2-way communication; other systems use a simpler 1-way communication. Information can be transmitted from a central communications center or from roadside transmitters. The DAIR system is very sophisticated compared to other systems in that many options are available. The DAIR system informs the driver of speed and traffic signs, allows him to summon help in an emergency, and provides automatic routing for his trip.

A subsystem of the DAIR system is the simple roadside communication link. An induction loop is used to give preprogrammed messages concerning traffic conditions, regulatory signs, and warning signs. This subsystem is the basis of most other radio communication systems. The Georgia Institute of Technology tested such a system along a 10-mile section of the Kentucky Turnpike (9, 10). Acceptance by the user of the system was good.

Another type of in-car device uses visual messages. These devices also use short-range roadside communications. An Experimental Route Guidance System (ERGS) was developed by General Motors for the Federal Highway Administration (12). This system utilizes a dashboard visual display to give routing directions to a driver for a prespecified destination. When the driver enters his vehicle, he dials the code number of his destination into his ERGS console. As the driver approaches an intersection, the dashboard display gives the necessary information concerning which lane to use and when and where to turn. Because the system is destination-oriented rather than route-oriented, driver errors are easily corrected. If a driver misses a turn, he is simply given directions on how to reach his destination from the next intersection.

An improvement over the dashboard display is the head-up display (13). The head-up display is a technique developed as a pilot landing aid. This concept utilizes an image superimposed on the real world. That is, it is possible to display words or symbols or both such that a driver can read the message and still be watching the road. This system was designed as an extension of the ERG System. It has the advantage of not distracting the driver or blocking his vision. It also has a set of 16 basic directional symbols developed by the Federal Highway Administration for route guidance.

Real-Time Information Systems

Several recent projects have been concerned with real-time information for drivers. Heathington used an attitudinal survey (14, 15, 16) to evaluate driver attitudes toward a freeway driver information system (FDIS). The research included an evaluation of the willingness of Chicago area drivers to pay for an information system on Chicago expressways, an evaluation of the likelihood of diversion to alternative routes when given specific information on freeway conditions, and an evaluation of the specific messages to be used for 3 levels of congestion. The transportation improvement considered most important by the Chicago drivers surveyed was the improvement of the riding surface on expressways. More important, the provision of electronic signs giving information on traffic conditions rated second. This indicates the importance that Chicago drivers placed on real-time information. With regard to the specific sign messages on the FDIS, the respondents indicated a preference for traffic information over nontraffic information at all levels of congestion. Therefore, even if no congestion exists, the drivers want to be told that no congestion exists rather than to be told nothing.

Hoff looked at alternative methods of communicating with drivers (17). The purpose of his research was to look at different traffic information techniques that might be used to divert drivers around congested areas of the highway system. A questionnaire was developed to determine the preference of drivers for 6 alternative methods of communication. The ordered preference of Chicago drivers for methods of receiving information concerning freeway conditions was as follows: changeable-message sign, symbolic map with arrows and streets, symbolic map with arrows, commercial radio, roadside radio, and experience.

Dudek and Jones also evaluated real-time visual displays for urban freeways (18). This research was directed toward the development of functional requirements for a real-time freeway communication system for urban areas. The researchers felt that it was essential that the motoring public play a major role in establishing the functional requirements of the system inasmuch as the system must fulfill their needs. Their research was directed toward evaluating driver attitudes concerning the need for real-time information, potential use and response to real-time information, driver preferences for mode of communication, type of information desired, priorities for the location of information, and driver comprehension of and preferences for visual displays. This work was patterned after the work of Heathington and Hoff (4, 17). The surveyed Texas drivers were given 3 alternatives for real-time information: real-time information, additional guide signs, and other (to be filled in by the respondent). The results indicated a preference for real-time information over additional guide signs. Only a small number of respondents filled in an alternative type of system. Their findings also indicated that Texas drivers preferred simple descriptive and color-coded displays over more complicated displays involving diagrams.

Dudek and Cummings also evaluated alternative information systems (19). The main objective of this study was to investigate the application of commercial radio to freeway communication. As a part of this study, alternative modes of communicating with drivers were evaluated by the use of an attitudinal questionnaire. This survey of Texas drivers indicated the following order of preference for urban freeway information: radio, signs, television, and telephone. They concluded, however, that no appreciable difference existed between the radio and the sign modes.

This previous research concerning driver-information systems seems to indicate that improved driver communication is desired. A logical extension of this previous research would be the application of the technology developed to other traffic situations. One extension of this previous research is the evaluation of advance-warning systems for railroad grade-crossing protection. The ERG type of system could be used to give drivers inside vehicles visual information concerning hazards at railroad crossings and at other highway locations. A roadside radio communication system could also be used to provide audio warning messages. Finally, a changeable-message, advance-warning sign could be used to provide advance warning at highway-railway grade crossings.

DESIGN OF RESEARCH

The broad goal of this research was to explore new concepts in the design of a driver-information system for highway-railway grade crossings. Several specific objectives related to the overall design, and desirability of new concepts was utilized for improving safety at highway-railway grade crossings.

The first objective was to evaluate driver attitudes concerning the hazards at railroad grade crossings. It was decided that driver attitudes concerning grade crossings could best be evaluated relative to other similar highway hazards. Six hazards were selected for evaluation.

The second objective of this research was to evaluate the economic priorities for improving railroad grade crossings relative to 8 other highway improvements of approximately the same cost.

The third objective was to evaluate driver preferences for specific information systems to be used at highway-railway grade crossings. Three new systems were evaluated that involved a changeable-message sign, an in-car visual display, and an in-car audio message. The changeable-message sign was an overhead whose displays changed depending on conditions. The in-car devices were patterned after the ERG and DAIR systems (12, 11). In addition, 2 currently used warning systems were included in the analysis to provide a comparison between present and proposed systems. The present systems were the active type of protection represented by automatic flashing lights and the passive type of warning sign.

The fourth objective of this research was to evaluate driver preferences for alternative messages to be used in a driver information system for highway-railway grade crossings. Several messages were evaluated for their desirability. An analysis was made for 2 conditions: when a train is present and when the railway tracks are clear.

The research method selected for accomplishing the specific objectives was an attitudinal survey of drivers. This is certainly not the only method of research that could have been used for the evaluation. The more commonly used method in traffic engineering involves field-testing. One can construct a system and then evaluate various aspects through alteration of the system during a period of time. This is an expensive procedure and often does not permit sufficient variation in system design for proper evaluation.

One can evaluate several alternatives more quickly and at a much lower cost by the use of an attitudinal survey than by actual field construction. This type of attitudinal research is not intended to replace final field evaluation of any system. The purpose of the attitudinal research is simply to aid in the planning and design of the best possible warning system as quickly, as efficiently, and as economically as possible.

Two psychological scaling techniques were selected for obtaining driver attitudes (20, 21). The method of paired comparisons was selected for its ability to establish a relative ranking of various alternatives, and a rating scale was also used to establish an absolute scale. These 2 techniques have been used extensively in the area of transportation research by General Motors, Heathington, Hoff, and MacGillivray (22, 14, 15, 16, 17, 23).

Data Collection

Ideally, a systematic random sample would be drawn from the population of Indiana drivers. An alternative approach was necessary because of resource limitations. The method of data collection chosen was to administer the questionnaire to groups from various segments of the driving population in the Lafayette, Indiana, area. A total of 259 drivers were interviewed.

The groups chosen for administration of the questionnaire were members of the Lions Club of Lafayette, clerical employees of State Farm Insurance Company (non-automobile divisions), members of a Lafayette Army Reserve Unit, Purdue University undergraduates, Wainwright High School students (Tippecanoe County), Central Catholic High School students (Lafayette), and Southwestern High School students (Tippecanoe County).

Table 1 gives some characteristics of the 259 respondents. The important aspect to note is that a large range of social and driving characteristics are represented in the sample. Approximately 81 percent of the respondents were males, and 19 percent were females. Approximately one-third of the respondents were under age 20, approximately one-third were age 20 to age 29, and approximately one-third were over age 29. Respondents without a high school diploma represented approximately one-third of the total respondents, and high school and college graduates each represented approximately one-third of the total number of respondents. Approximately 50 percent of the respondents drove fewer than 10,000 miles/year, and approximately 50 percent drove more than 10,000 miles/year.

DRIVER ATTITUDES TOWARD HIGHWAY HAZARDS

The first objective of this research was to evaluate driver attitudes concerning the hazard at highway-railway grade crossings. A survey of the 259 drivers was made to determine attitudes on a relative scale and on an absolute scale. The relative scale indicates how hazardous the drivers considered railroad grade crossings to be relative to several other hazards. The absolute scale indicates whether the drivers considered railroad grade crossings and the other alternative hazards to be very hazardous, not very hazardous, or somewhere in between.

Six highway hazards were selected for analysis: railroad grade crossing, signalized intersection, stop-controlled intersection, yield-controlled intersection, uncontrolled intersection (crossroad), and curve. Five of the 6 hazards are intersections with various types of control.

The railroad grade crossing is unique in that it is the intersection of 2 modes of transportation with vastly differing operating characteristics. One of the important differences is the inability of the trains to stop in a short distance. Railroad trains require such large stopping distances that they are always given the right-of-way. Another difference is that a relatively small number of trains pass over a grade crossing each day. The advance-warning sign for a railroad grade crossing is the same for crossings with automatic signals and for crossings with only signs.

A signalized intersection alternately assigns the right-of-way to each road or street. It also gives an identifiable yellow clearance interval that indicates that the right-of-way is changing. Unlike the railroad engineer, the defensive driver may give up his right-of-way to another driver.

A stop-controlled intersection requires the driver to relinquish the right-of-way to cross-street traffic. Typically, a major street is given a constant right-of-way in preference to the stop-controlled minor street. A yield-controlled intersection indicates the need to stop only when a vehicle is approaching on the cross street. Finally, a crossroad as presented in this research is a through road intersected by a high-volume road. The crossroad sign is erected only when sight distance is restricted on the through road.

The final hazard evaluated was a simple highway curve. The hazard presented in this research is a curve without any advisory speed reduction.

All 6 hazards in this research require advance-warning signs for restricted sight distance. The advance-warning sign for railroad grade crossings is required at almost all crossings with the following exceptions: (a) at a minor siding or spur that is infrequently used and when in use is guarded by a member of the train crew, and (b) at crossings in business districts where there is full protection and where physical conditions make even partially effective display of the sign difficult.

Methods of Evaluation

The method selected to obtain the necessary driver attitudes was a structured questionnaire that used psychological scaling techniques. Two psychological scaling techniques, the method of paired comparisons and a rating scale, were used to evaluate the respondents' attitudes toward each of the 6 hazards. The method of paired comparisons was used to establish relative ranking of the hazards. The rating scale was used to establish absolute importance of each hazard.

The method chosen to present these 6 hazards to the 259 respondents was photographs of the standard advance-warning sign. The photographs were taken of the advance-warning sign properly mounted along a 2-lane state highway. All signs were photographed at the same location, as shown in Figure 1, so that all possible effects of the highway scene would be the same for all hazards. The location was selected such that any hazard could exist just beyond the crest of a small hill.

The respondents were never informed that this research was primarily concerned with railroad grade crossings.

Relative Scaling for Highway Hazards

The paired-comparison technique was used to evaluate the 6 hazards. The number of pairs necessary for the paired-comparison analysis is $n(n - 1)/2$, where n is the number of alternatives; therefore, 15 pairs of hazards are required. Because of several possible sources of error, the pairs were presented in a different random order to each group of respondents. This randomization reduced the effect of the tendency of people to always pick the first (or second) response and to become tired after seeing a large number of pairs of alternatives. That is to say, if a specific pair was given last to one group, it may have appeared first to another group.

Two synchronized 35-mm slide projectors displayed 2 slides of hazards side by side on 2 screens (Fig. 2). The hazard shown on the screen to the left was labeled A, and the hazard on the screen to the right was labeled B. The first 2 slides shown were an example. Slide A was a truck-crossing, and slide B was a hill. The respondents were instructed to assume that they were driving along a highway. If they thought a truck-crossing was a more hazardous situation, they were to circle the letter A on their answer sheets. If they felt that a hill and a truck-crossing were equally hazardous, they were to arbitrarily select either A or B.

After the example was given and questions were answered, the 15 pairs of hazards were shown for 12 sec; after that, there was a 3-sec interval in which nothing was shown. This 3-sec interval indicated the end of the allotted time and allowed a period to mark the appropriate answer. Although the time allowed seems short, it was found during the pretest that this length of time was quite adequate.

The results of the paired-comparison analysis of the 6 hazards for all 259 respondents are shown in Figure 3. The railroad grade crossing was the most hazardous situation with a relative scale value of 0.59.

Thurston suggests that, if the paired-comparison assumptions are adequately met, then one should be able to work backward from the scale values and recreate the originally observed proportions (20). Ideally, these calculated proportions would be identical to the observed proportions. Therefore, if a good fit of the observed data is made, a plot of the observed proportions (P'_{ij}) versus the calculated proportions (P''_{ij}) should approach a 45-deg straight line through the origin. The better the fit is, the closer the data will approach a straight line. Figure 4 is a plot of the calculated versus the observed proportions for all respondents. The plot indicates a reasonably good fit of the model to the data.

Another indicator of the validity of the model is obtained by a least squares fit of the P'_{ij} versus P''_{ij} data points. The assumptions of a linear model are not necessarily met, but the slope, intercept, and simple correlation provide an indication of the validity of the paired-comparison model. That is, the slope of the fitted line should be 1.00, the intercept 0.00, and the correlation 1.00 if the paired-comparison model is a perfect fit of the observed data. For the plot shown in Figure 4, the slope is 0.93, the intercept is 0.04, and the correlation is 0.96. This indicates a reasonable fit of the data by the paired-comparison model.

Relative Scaling by Subgroups for Highway Hazards

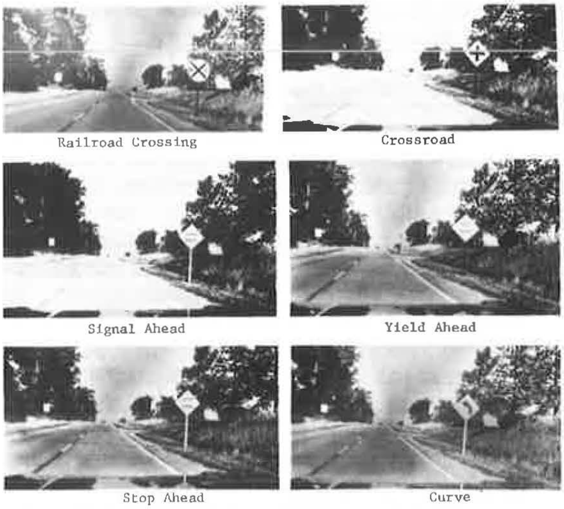
In designing an advance-warning system for highway-railway grade crossings, one finds it helpful to know whether any subgroups of respondents have different attitudes concerning the hazards. If any major subgroups have attitudes different from those of the respondents as a whole, then any design would have to take the differences into account. Therefore, the sample was divided into 4 subgroups. The subgroups were based on sex, miles driven per year, education, and age. These 4 subgroups were further divided into the following 11 categories for analysis: males, females, under 7,500-mile/year drivers, 7,500- to 12,500-mile/year drivers, over 12,500-mile/year drivers, high school graduates, non-high school graduates, college graduates, 19 year olds or under, 20 to 29 year olds, and 30 year olds or over.

Table 1. Characteristics of respondents.

Characteristic	Number	Percent
Sex		
Male	209	80.7
Female	50	19.3
Total	259	100.0
Age		
Under 20	94	36.3
20 to 24	59	22.8
25 to 29	26	10.0
30 to 34	6	2.3
35 to 39	11	4.3
40 to 49	28	10.8
50 to 59	19	7.4
60 to 69	13	5.0
70 or over	3	1.1
Total	259	100.0
Education		
1 to 8 years of grade school	2	0.8
1 to 3 years of high school	86	33.2
Graduated from high school	32	12.4
1 to 2 years of college or trade school	51	19.7
Graduated from college	47	18.1
Completed graduate degree	41	15.8
Total	259	100.0
Miles driven annually		
Under 5,000	66	25.5
5,000 to 7,500	34	13.1
7,500 to 10,000	32	12.4
10,000 to 12,500	44	17.0
12,500 to 15,000	33	12.7
Over 15,000	50	19.3
Total	259	100.0
Income		
Under 2,500	7	2.7
2,500 to 5,000	20	7.7
5,000 to 7,500	16	6.2
7,500 to 10,000	21	8.1
10,000 to 12,500	17	6.6
12,500 to 15,000	23	8.9
15,000 to 17,500	15	5.8
17,500 to 20,000	17	6.6
Over 20,000	29	11.2
Not asked[a]	90	34.7
Refused	4	1.5
Total	259	100.0

[a] High school and college students not asked.

Figure 1. Highway hazards.



Railroad Crossing

Crossroad

Signal Ahead

Yield Ahead

Stop Ahead

Curve

Figure 2. Paired-comparison presentation.

A

B

Figure 3. Relative scale for highway hazards.

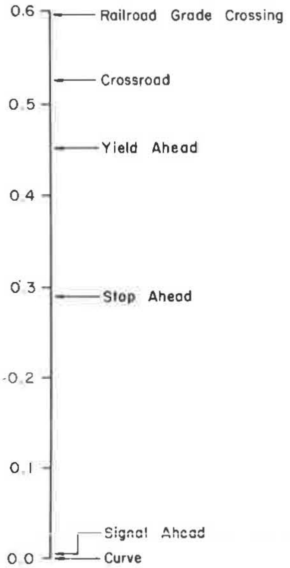
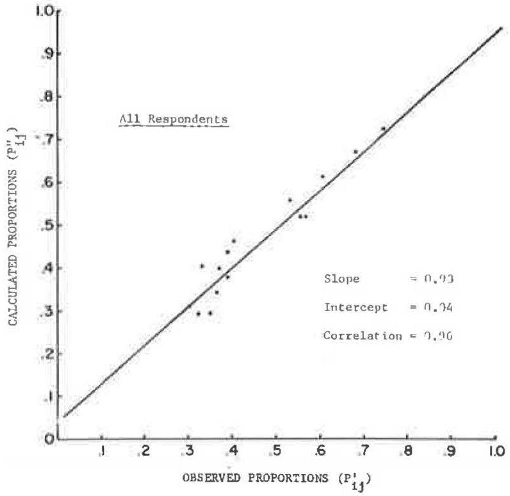


Figure 4. Calculated versus observed proportions for highway hazards.



It was found that only very minor changes occur in the relative ranking among subgroups. Only 3 subgroups did not rate railroad crossings as most hazardous. Those driving more than 12,500 miles/year and college graduates rated it second to a crossroad. Respondents aged 20 to 29 considered railroad grade crossings to be the third most hazardous situation, a crossroad to be the first, and a yield-controlled intersection to be second. Even in these 3 cases, railroad grade crossings rated very high on the relative scale. In all categories of subgroups, the stop-controlled intersection was rated fourth. Also, the signal-controlled intersection and the curve were rated as the 2 least hazardous situations by all the categories of subgroups.

A visual inspection of the plot of P'_{ij} versus P''_{ij} was made for all subgroups. No serious departures from a 45-deg straight line were found in any categories of subgroups except in the females, under 20 year olds, non-high school graduates, and under 7,500-mile/year drivers. Again, the least squares fit is only an indication that aids in the evaluation of the P'_{ij} versus the P''_{ij} plot. Although it would be questionable to accept the results of the 3 subgroups mentioned, the results were in general agreement with the other subgroups.

Absolute Scaling for Highway Hazards

The paired-comparison analysis indicated that railroad grade crossings were relatively more hazardous than the other 5 hazards. A rating scale was used to indicate how hazardous grade crossings rate on an absolute scale.

After the 259 respondents completed the paired-comparison questions, they had seen each of the 6 hazards a total of 5 times. They were, therefore, familiar with the 6 hazards. They were now asked to rate each hazard individually. The respondents were told they would be shown each of the 6 hazards one at a time. They were told to indicate how hazardous they felt each situation was by marking a number from 1 (not very hazardous) to 7 (very hazardous).

Table 2 gives the mean, the standard deviation, and the distribution of responses for the 259 respondents. The crossroad, the yield-controlled intersection, the railroad crossing, and the curve were considered to be only moderately hazardous. The mean ranged from a high of 4.93 for the crossroad to a low of 4.22 for the curve. The distribution of responses also shows that only about 18 percent of the respondents rated any of the 4 hazards with the highest value of 7. A value of 4 on the rating scale can be taken as indifference. The respondents were, therefore, indifferent about the hazard at stop-controlled intersections and considered signalized intersections to be less than hazardous.

Absolute Scaling by Subgroups for Highway Hazards

The same subgroups used in the paired-comparison analysis were again used in the rating scale analysis. The results for all the subgroups indicated that the situations were only moderately hazardous.

A contingency test was used to determine whether the distribution of responses was independent of the subgroups. Only for the age subgroup was the hypothesis of independence rejected at an alpha level of 0.01 for both the railroad crossing and the curve. Railroad crossings were rated less hazardous as age increased. Also, those over age 29 found a curve more hazardous than did those under age 20, while those between age 20 and age 29 felt a curve to be least hazardous.

Summary

Railroad grade crossings are considered by the respondents to be relatively more hazardous than signalized intersections, yield-controlled intersections, crossroads, and curves. However, the respondents considered only 4 of the 6 highway situations to be even moderately hazardous. An analysis of responses of 4 subgroups and those of the entire group of 259 respondents resulted in the same conclusions. This lack of concern for hazardous conditions existing on highways might account for the problems of safety at many of the highway-railway grade crossings.

PRIORITIES FOR ALLOCATING HIGHWAY TAXES

The second objective of this research was to evaluate driver priorities for improving the safety at railroad grade crossings and several other highway improvements. The 8 areas were as follows:

1. Improve warning devices at railroad grade crossings,
2. Improve the road surface on major highways,
3. Improve signs giving directions,
4. Provide mowing of grass along the sides of highways,
5. Install more traffic lights,
6. Improve roadside rest areas,
7. Improve maintenance of painted lines on roads, and
8. Provide free emergency telephones that are connected only to the highway department and to the police department.

The method of evaluation chosen was a rating scale above which each item was written. Respondents were told to indicate the importance of each item in receiving highway taxes. The scale ranged from 1, which indicated the item was unimportant, to 7, which indicated that the item was important.

Driver Preferences for Highway Improvements

The results of the rating scale for the 259 respondents are also given in Table 2. The numbers shown are the distribution of responses, the average responses, and the standard deviations. The respondents gave the improvement of the road surface the highest average rating of 5.77. The standard deviation was 1.38. Only 16 percent of the respondents gave a rating of 4 or less to this improvement. This result agrees with work done by Heathington, who found that Chicago drivers also considered the repair of pavement the most important of 10 alternative transportation improvements for expressways (15).

Improving the safety at railroad grade crossings received an average rating of 5.74. The standard deviation was 1.47.

Third with an average rating of 5.42 was the improvement of the maintenance of painted lines. The standard deviation was 1.58. Fourth with an average rating of 4.97 and a standard deviation of 1.62 was the improvement of signs giving directions. Improvement of directional signs, therefore, could only be considered moderately important. Just below the improvement of directional signs is the provision of emergency telephones along highways. This item had a mean rating of 4.84 and a standard deviation of 1.86. It also could be considered moderately important. Rated sixth with a mean of 4.05 and a standard deviation of 1.64 was the installation of more traffic lights. At best, installing more traffic signals could only be considered slightly important. The remaining 2 items have ratings below the indifference point of 4. Rated seventh with a mean of 3.76 and a standard deviation of 1.82 was the improvement of roadside rest areas. Last with a mean of 3.16 and standard deviation of 1.69 was the provision of the mowing of grass along the sides of highways.

Driver Preferences by Subgroups for Highway Improvements

A contingency test was made to determine whether the distribution of responses was independent of the subgroups. The hypothesis of independence is rejected in 2 subgroups at an alpha level of 0.01: the education subgroup for the improvement of road surfaces and the age subgroup for the improvement of the maintenance of painted lines.

The improvement of road surfaces is considered to be most important by high school graduates, less important by non-high school graduates, and least important by college graduates. The ratings ranged from 5.44 to 6.18 for the 3 education categories. This indicates a high degree of importance by all the respondents for the improvement of the maintenance of road surfaces.

The improvement of the maintenance of painted lines was considered more important as age increased. The average rating of 6.0 for those over age 29 was nearly a full scale division above an average of 5.18 for those age 20 to age 29 and an average of 5.17 for those under age 20. The average of 6.0 indicates a very high degree of importance for the maintenance of painted lines for those over age 29. The remainder of the respondents only considered painted lines to be moderately important.

Summary

The improvement of safety at railroad grade crossings was considered very important by the 259 respondents. The respondents also considered it important that highway taxes be spent on the improvement of road surfaces and the improvement of the maintenance of painted lines. A moderately important priority was given to the improvement of directional signs and the provision of emergency telephones. The improvement of roadside rest areas and the mowing of grass along the sides of highways were both rated as relatively unimportant.

DRIVER PREFERENCES FOR WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

The 3 new advance-warning systems used in this study are based on research previously discussed. Two proposed systems used visual communication. A changeable-message, advance-warning sign was the result of work on an FDIS (14). A device similar to the dashboard display of ERGS was used to provide a visual in-car message (12). The third and last system was an audio in-car message. This system was patterned after the roadside communication subsystem of the DAIR system (11). An audio-warning system external to the vehicle was not considered in this research.

Two existing systems were included in the analysis: One was the active flashing lights, and the other was a passive system consisting only of warning signs. All 5 warning systems are shown in Figure 5. The same highway scene was used with the appropriate warning devices being photographically added.

Relative Scaling of Warning Systems

The method of paired comparisons was used to evaluate relative preferences of drivers for the 5 alternative warning systems for use at grade crossings. The respondents were shown the 5 hazards 2 at a time. A total of 10 pairs of hazards were shown. The respondents were asked to indicate which of the 2 warning devices was more desirable.

Figure 6 shows the results of the ranking by the 259 respondents. By far the most desirable method of warning was the changeable-message sign. It had a relative ranking of 1.39. The least desirable method of warning was the passive warning sign with a relative rating of 0.00.

Observed proportions P'_{ij} were plotted against the calculated proportions P''_{ij} (Fig. 7). The plot indicates a reasonable approximation of a 45-deg straight line through the origin. Another indicator used to evaluate the model was a least squares fit of the P'_{ij} versus P''_{ij} data. If the model is an exact fit, the slope will be 1.00, the intercept will be 0.00, and the simple correlation will be 1.00. The actual results indicated a slope of 1.00, an intercept of -0.02, and a correlation of 0.99. These results tend to indicate a good fit of the observed data by the paired-comparison model.

Relative Scaling by Subgroups of Warning Systems

An analysis was made for the same subgroups as in previous parts of the research. The results indicate general agreement for all subgroups. The changeable-message sign was rated first by all subgroups. The first choice was also well above the second rated standard flashers. The third and fourth choices for all subgroups were the in-car devices. Most subgroups rated the audio device above the visual device. Those respondents who drove more than 12,500 miles/year and those over age 29 rated the visual in-car device over the audio device. The least preferred method of warning for all subgroups was the passive warning sign.

Table 2. Mean, standard deviation, and distribution of responses.

Item	No Response		Rating 1		Rating 2		Rating 3		Rating 4		Rating 5		Rating 6		Rating 7		Mean	S D
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent		
Hazard																		
Signal ahead	1	0.4	18	6.9	56	21.6	63	24.3	75	29.0	30	11.6	12	4.6	4	1.5	3.37	1.34
Stop ahead	1	0.4	27	10.4	29	8.5	41	15.8	52	20.1	50	19.3	30	11.6	29	11.2	4.00	1.80
Railroad crossing	2	0.8	13	5.0	22	8.5	35	13.5	47	18.1	48	18.5	54	20.8	38	14.7	4.59	1.72
Yield ahead	1	0.4	6	2.3	28	10.8	26	10.0	50	19.3	68	26.2	54	20.8	26	10.0	4.60	1.55
Curve ahead	1	0.4	19	7.3	37	14.3	32	12.4	52	20.1	47	18.1	40	15.4	31	12.0	4.22	1.79
Crossroad	2	0.8	6	2.3	15	5.8	27	10.4	47	18.1	56	21.6	59	22.8	47	18.1	4.93	1.57
Improvement																		
Traffic lights	3	1.1	19	7.3	29	11.2	43	16.6	63	24.3	53	20.5	28	10.8	21	8.1	4.05	1.64
Road surface	4	1.5	3	1.1	6	2.3	9	3.5	25	9.7	43	16.6	68	26.2	101	39.0	5.77	1.38
Directional signs	4	1.5	7	2.7	11	4.2	30	11.6	51	19.7	51	19.7	46	17.8	59	22.8	4.97	1.62
Mowing grass	4	1.5	41	15.8	68	26.2	51	19.7	42	16.2	25	9.7	13	5.0	15	5.8	3.16	1.69
Railroad crossings	4	1.5	3	1.1	8	3.1	12	4.6	26	10.0	42	16.2	53	20.5	111	42.8	5.74	1.47
Rest areas	4	1.5	35	13.5	38	14.7	40	15.4	54	20.8	38	14.7	27	10.4	23	8.9	3.76	1.82
Painted lines	5	1.7	2	0.8	14	5.4	18	6.9	38	14.7	42	16.2	49	13.9	91	35.1	5.42	1.53
Emergency telephones	6	2.3	18	6.9	19	7.3	19	7.3	43	16.6	46	17.8	45	17.4	63	24.3	4.34	1.36
Warning system																		
Passive sign	0	0.0	36	13.9	47	18.1	50	19.3	68	26.2	35	13.5	14	5.4	9	3.5	3.37	1.57
Flashing lights	1	0.4	5	1.9	10	3.9	17	6.6	46	17.8	65	25.1	56	21.6	59	22.8	5.17	1.49
Changeable-message sign	1	0.4	4	1.5	3	1.1	15	5.8	19	7.3	22	8.5	49	18.9	146	56.4	6.03	1.43
In-car visual	0	0.0	42	16.2	18	6.9	31	12.0	46	17.8	57	22.0	40	15.4	25	9.7	4.07	1.89
In-car audio	0	0.0	45	17.4	22	8.5	21	8.1	39	15.1	49	17.8	48	18.5	35	13.5	4.19	2.03
Alternative display																		
No. 1	1	0.4	17	6.6	57	22.0	45	17.4	56	21.6	43	16.6	24	9.3	16	6.2	3.72	1.64
No. 2	0	0.0	8	3.1	11	4.2	36	13.9	62	23.9	60	23.2	53	20.5	29	11.2	4.66	1.49
No. 3	1	0.4	1	0.4	2	0.8	4	1.5	14	5.4	28	10.8	80	30.5	129	49.8	6.19	1.08
No. 4	1	0.4	1	0.4	2	0.8	8	3.1	10	3.9	36	13.9	77	29.8	125	48.8	6.12	1.12
No. 5	0	0.0	14	5.4	34	13.1	47	18.1	54	20.8	49	18.9	31	12.0	30	11.6	4.17	1.70

Figure 5. Warning systems for highway and railway grade crossings.

Figure 6. Relative scale for warning systems.

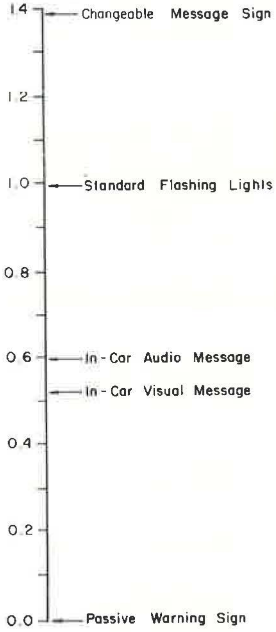
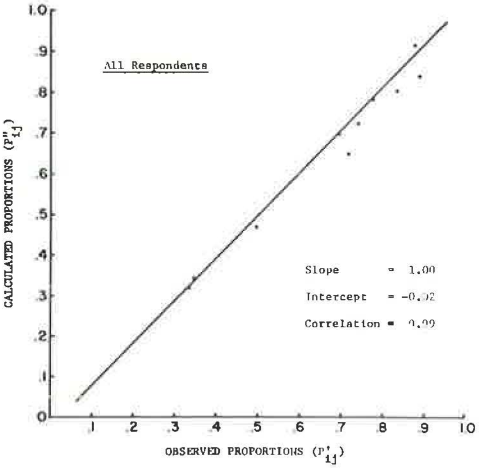


Figure 7. Calculated versus observed proportions for warning systems.



Plots were made of the P'_{ij} versus P''_{ij} for all subgroups and indicated a good fit of the data. A least squares fit of the P'_{ij} versus P''_{ij} was also made as an indicator of the validity of the model. These results also indicated a relatively good fit of the paired-comparison model to the data for all subgroups.

Absolute Scaling of Warning Systems

The paired-comparison analysis gave a relative scale indicating that a changeable-message sign was the most desirable of 5 alternative methods of warning. It is also important to know on an absolute scale the desirability of the warning systems. The method of evaluation selected was a rating scale as previously used. The respondents were shown a slide of a warning system and told to mark their response on the rating scale. The scale ranged from 1 (undesirable) to 7 (desirable). After completion of the paired-comparison question, the respondents were shown the 5 methods of warning one at a time. They were told to indicate their response on the appropriate scale on the answer sheet.

The results are given in Table 2 for all 259 respondents. The changeable-message sign had a mean rating of 6.03 and a standard deviation of 1.43. It was given the highest rating of 7 by more than 56 percent of the respondents. The changeable-message sign was considered to be a very desirable method of warning by the majority of the respondents.

The standard flashing lights had a mean of 5.17 and a standard deviation of 1.49. The flashers were nearly a full scale division below the changeable-message sign and could be considered moderately desirable.

Lower on the scale with a mean of 4.19 and a standard deviation of 2.03 was the in-car visual message. The in-car audio message had a mean of 4.07 and a standard deviation of 1.89. At best, the respondents considered the in-car devices as slightly desirable. The passive sign was rated lowest with a mean of 3.37 and a standard deviation of 1.57 and was, therefore, considered to be not desirable by the majority of the respondents.

Absolute Scaling by Subgroups of Warning Systems

A rating scale for the 11 subgroups was developed, and the results are generally the same for all subgroups. The changeable-message sign was rated very desirable by all subgroups.

A contingency test was also made to determine whether the distribution of responses was independent of the subgroup. The hypothesis of independence was not rejected at an alpha level of 0.01 for any subgroups. There is no reason to believe that any of the subgroups had different preferences for methods of warning.

Summary

The overhead changeable-message sign was the most preferred alternative method of warning by the 259 respondents. It was also considered to be very desirable by all the subgroups. In-car devices were rated lower than present flashers. The least preferred method of warning is a passive sign that indicates the same warning at all times.

DRIVER PREFERENCES FOR ALTERNATIVE DISPLAYS FOR USE IN ADVANCE-WARNING SYSTEMS FOR HIGHWAY-RAILWAY GRADE CROSSINGS

Alternative information systems were also evaluated by the use of paired comparisons and a rating scale. The evaluation of the alternative messages was made in 2 parts. The first part concerned messages to be used when a driver had to stop because of the presence, or imminent presence, of a train. The second part concerned messages to be used when there was no train. The simplest alternative for the second condition is to provide no message. If this alternative were accepted, then no analysis would be necessary. It was decided, however, to evaluate the no-message alternative with several messages indicating that no hazard existed.

Relative Scaling for Alternative Displays When a Hazard Exists

Five alternative messages were selected for possible use when a train is blocking the highway or so close to the crossing that it constitutes an imminent hazard to approaching vehicles. The actual messages shown to the respondents are shown in Figure 8. The respondents were shown the 5 messages 2 at a time with the use of 2 synchronized 35-mm slide projectors. A total of 10 pairs of messages were shown. The respondents were asked to indicate which of the 2 messages was the more desirable.

The paired-comparison technique was used to evaluate the relative acceptability of the 5 alternative displays. The results for the 259 respondents are shown in Figure 9. The most preferred display was No. 3; it identifies the hazard and tells the driver the necessary action to take. A close second with a 1.27 scale value was No. 4, which has essentially the same characteristics as No. 3.

Third rated was No. 2, and fourth was No. 5. The symbol is apparently recognized and seems to be preferred over the equivalent in words. Display No. 1 had a relative scale value of 0.0. Even with the stop-ahead instructions, this display received the lowest rating.

The observed proportions P'_{ij} were plotted against the calculated proportions P''_{ij} based on the paired-comparison model. The results are shown in Figure 10. A least squares fit of the P'_{ij} versus P''_{ij} matrix was also made as an indicator of how well the model fitted the data. The results were an intercept of 0.02, a slope of 0.95, and a correlation of 0.99. If the model perfectly fits the data, the intercept will be 0.00, the slope will be 1.00, and the correlation will also be 1.00. The results indicate a reasonably good fit of the observed data by the paired-comparison model.

Relative Scaling by Subgroups for Displays When a Hazard Exists

The alternative displays were analyzed to see whether any subgroups had different preferences. The results of all the subgroups are in general agreement, except for 3 minor exceptions. Those who drive over 12,500 miles/year and those age 20 to age 29 rated display No. 4 first. The display most preferred by all other subgroups was rated such a close second that any difference in results is minor. The third difference is that females interchanged the fourth and fifth rated displays. This difference is minor, for the concern is with the more preferred displays.

The P'_{ij} versus P''_{ij} matrix was also plotted for all subgroups. The paired-comparison model was a reasonable fit of the data for all categories of subgroups. There is no reason not to accept the results of the paired-comparison analysis for all categories of subgroups.

Absolute Scaling for Alternative Displays When a Hazard Exists

A rating scale was used to determine an absolute scale for the 5 alternative displays for an advance-warning system when a hazard exists. The 5 displays were shown to the 259 respondents one at a time. They were asked to indicate, on a scale from 1 to 7, how acceptable they considered each alternative display. The higher the number indicated, the more acceptable the respondents considered the display to be.

The rating scale results are given in Table 2. Display No. 3 was considered to be very acceptable with a mean rating of 6.19 and a standard deviation of 1.08. Also rated very acceptable with a mean of 6.12 and a standard deviation of 1.12 was display No. 4. These 2 alternatives are very similar in absolute preference.

Display No. 2 had a mean of 4.66 and a standard deviation of 1.49. This display could be considered as moderately acceptable. Display No. 5 could only be considered slightly acceptable. It had a mean of 4.17 and a standard deviation of 1.70. Display No. 1 was considered unacceptable by the respondents. The mean rating was 3.72 and the standard deviation was 1.64.

Absolute Scaling by Subgroups for Displays When a Hazard Exists

The 11 categories of the 4 subgroups were again used to determine whether any subgroups had different ratings for the displays. The results are in general agreement with the results for all respondents. Display No. 3 was rated very desirable by all subgroups. The average rating was above 6.00 for all categories of all subgroups.

A contingency test was also performed to determine whether the distribution of responses was independent of the subgroup at an alpha level of 0.01. The hypothesis of independence was rejected for only 1 subgroup. Males considered the lowest ranked display No. 5 as slightly more unacceptable than did the females.

Relative Scaling for Alternative Displays When No Hazard Exists

Five display alternatives were also selected for evaluation when no train was present and no imminent hazard existed. The alternatives are shown in Figure 11. Display No. 5 was a no-information alternative. Display No. 4 only identified the hazard and gave no other information. The remaining displays gave positive information that no hazard existed.

The paired-comparison technique was used to evaluate the relative acceptability of the 5 alternative displays. The results for the 259 respondents are shown in Figure 12. The most preferred display with a relative scale value of 1.78 was No. 1. A close second with a relative scale value of 1.73 was No. 2. These 2 displays parallel the most preferred displays when a hazard exists.

In third place was the display No. 3 with a relative scale value of 0.86. This again tends to indicate the preference for the standard symbol over the word message. The fourth rated display only contained the advance-warning symbol and had a relative rating of 0.80. The least desirable alternative was the display giving no information of any kind. The relative scale value was 0.0. This indicates that drivers do wish to be told when no hazard exists.

The validity of the results was checked by a plot of the observed proportions P'_{ij} versus the calculated proportions P''_{ij} based on the paired-comparison model. Figure 13 shows a reasonable fit of the data. A least squares fit was also made of the P'_{ij} versus P''_{ij} data. The results were an intercept of 0.10, slope of 0.86, and a correlation of 0.97. The results for a perfect fit would be 0.00, 1.00, and 1.00 respectively. The results are reasonable but not so good as those of some of the other models previously discussed. The difficulty in obtaining a good fit is caused by most proportions being at extreme values. That is, some alternatives were highly preferred and some were highly not preferred. However, the relative positions on the scale are reasonable ones.

Relative Scaling by Subgroups for Displays When No Hazard Exists

The alternative displays for the no-hazard condition were also analyzed to see whether any subgroups had different preferences. The results of all the subgroups are in general agreement except for 4 minor exceptions. Those respondents aged 20 to 29 and those who drive 7,500 to 12,500 miles preferred display No. 2 over display No. 1. The results are opposite those for all other groups, but the actual scale separation in all cases is very small. The third and fourth differences concern the same 2 subgroups. The third and fourth preferences of the 259 respondents are switched by these 2 subgroups. In all cases, the main concern is with the most preferred display; therefore, the importance of some of the scalings is reduced.

The P'_{ij} versus P''_{ij} matrix was plotted for all subgroups. These plots are not included because a least squares fit of the data indicates a reasonable fit of the observed data by the paired-comparison models.

Absolute Scaling for Alternative Displays When No Hazard Exists

Although the method of paired comparisons provided a relative scale of acceptability, the results did not indicate the degree of acceptability of the displays. A rating scale was, therefore, used to determine an absolute scale for the 5 alternative displays for the no-hazard condition. The technique was the same as that for the hazard-present condition.

Display No. 1 was considered very acceptable with an average rating of 5.82 and a standard deviation of 1.17. Thirty-four percent of the 259 respondents indicated the

Figure 8. Alternative displays when hazard exists at highway and railway grade crossings.

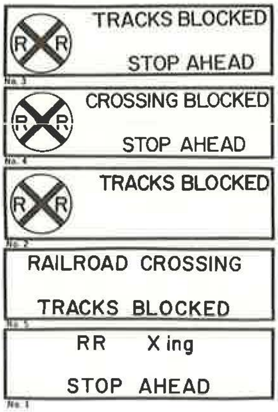


Figure 9. Relative scale for alternative displays when hazard exists.

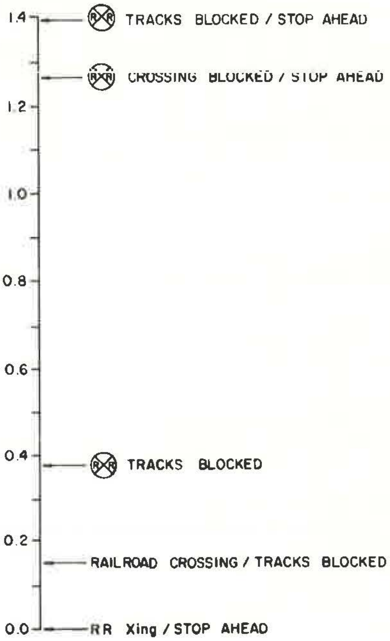


Figure 10. Calculated versus observed proportions for alternative displays when hazard exists.

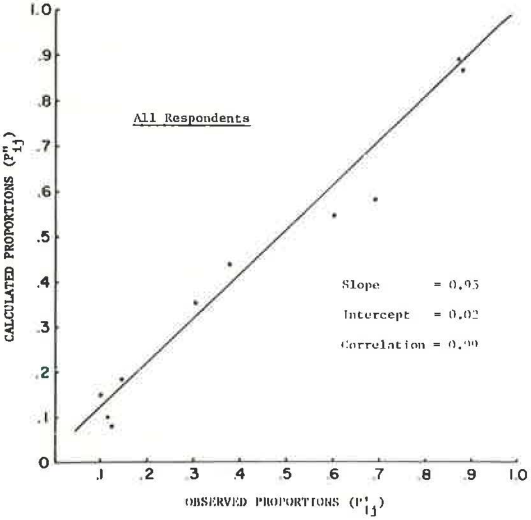


Figure 11. Alternative displays when no hazard exists at highway and railway grade crossings.

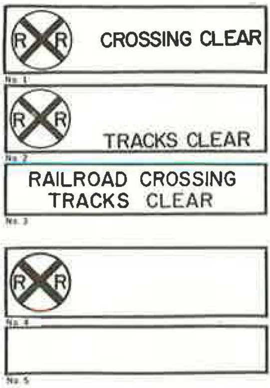


Figure 12. Relative scale for alternative displays when no hazard exists.

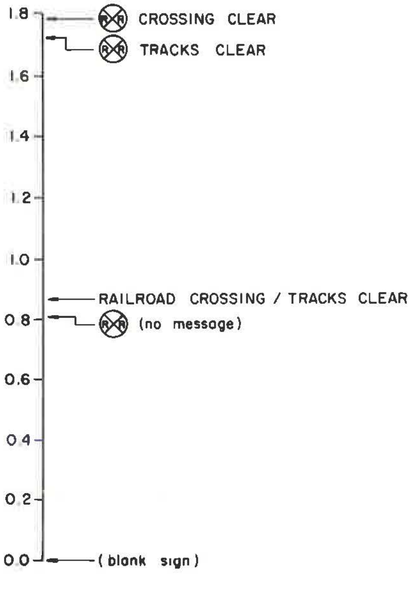
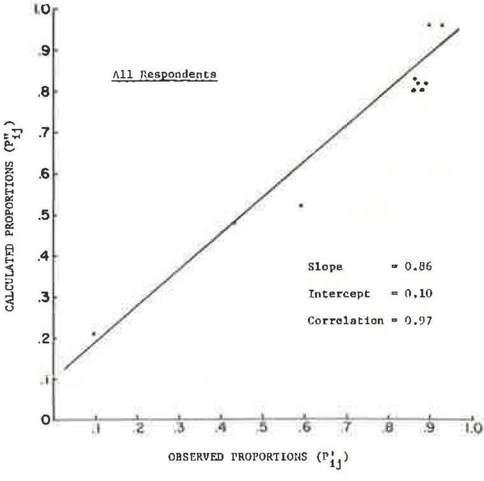


Figure 13. Calculated versus observed proportions for alternative displays when no hazard exists.



maximum rating of 7, and 86 percent gave a rating greater than 4. Also rated very acceptable with a mean of 5.68 and a standard deviation of 1.20 was display No. 2. Thirty-one percent indicated a rating of 7, and 81 percent gave a rating above 4.

Display No. 3 received a rating of 4.13 and had a standard deviation of 1.59. Only 6 percent more of the respondents rated the display above 4 than rated it below 4. At best the display is slightly acceptable.

The remaining 2 displays were rated undesirable. Display No. 4 had a mean of 3.53 and a standard deviation of 1.64. Fifty-one percent of the respondents rated it less than 4 on the scale. Display No. 5 had a mean of 1.75 and a standard deviation of 1.56. Seventy-three percent of the respondents rated it 1, the lowest possible score. Only 7.7 percent of the respondents rated it above 4. The respondents definitely desire information, even when no hazard exists.

Absolute Scaling by Subgroups for Displays When No Hazard Exists

The same categories of subgroups were again used to determine whether any subgroups had different feelings concerning the alternative displays when no hazard exists. Displays No. 1 and No. 2 are considered very acceptable by the 11 categories of the 4 subgroups. In all 11 cases for each display, the average rating was greater than 5.50. The results are in general agreement for all subgroups.

A contingency test was also performed to determine whether the distribution of responses was independent of the subgroup at an alpha level of 0.01. The hypothesis of independence was not rejected for any of the subgroups.

Summary

Alternative displays were evaluated for 2 situations: when a hazard exists at a grade crossing as the result of the presence of a train and when no hazard exists. For the hazardous condition, displays No. 3 and No. 4 were so closely rated that both alternatives are acceptable.

For the alternative situation when no hazard exists displays No. 1 and No. 2 were so closely rated that both alternatives are acceptable.

It would appear that drivers desire information even when no safety hazard exists. Drivers seem to prefer full words rather than abbreviations.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Railroad grade crossings were considered by the respondents to be relatively more hazardous than signalized intersections, yield-controlled intersections, crossroads, and curves. However, the respondents considered only 4 of the 6 highway situations to be even moderately hazardous. An analysis of responses of 4 subgroups resulted in the same conclusions.

Respondents considered it very important that safety be improved at railroad grade crossings and that highway taxes be used for this purpose. The respondents also considered it important that highway taxes be spent on the improvement of road surfaces. The improvement of roadside rest areas and the mowing of grass along the sides of highways were both rated as relatively unimportant.

An overhead changeable-message sign was the most preferred alternative method of warning drivers of a highway-railway grade crossing. It was also considered to be very desirable by all the subgroups. Various in-car devices were rated lower than currently used flashers. The least preferred method of warning is the passive sign that indicates the same warning at all times.

Alternative displays, including a no-information sign, were evaluated for use when a hazard exists at a grade crossing as the result of the presence of a train and also when no hazard exists. The respondents desired information even when no safety hazard exists and preferred wording rather than abbreviations.

The results of this research can be extended to the general driving public only to the extent that the 259 respondents utilized in the survey represent a broad cross section of drivers. However, it would seem that many of the principles covered in this research would be applicable particularly to the midwestern United States where highway-railway grade crossings are quite numerous.

The warning systems now in use at highway-railway grade crossings have changed very little since the beginning of the automobile age. It does not require research to prove that parts of the present warning systems are totally inadequate. Volumes and speeds on most major rural highways have increased so much during the past 60 years that warning systems that were adequate previous to 1920 are now outdated and ineffective. The insulation of sound in present-day automobiles makes many audible mechanisms less than adequate.

Under the existing liability regulations, the railroad companies are required to provide warnings and protection at highway-railway grade crossings. Because of right-of-way limitations, it is difficult for the companies to utilize adequate advance-warning systems. However, they have not been progressive in their thinking on warning systems. There has been virtually no new concepts in improving safety at highway-railway grade crossings by railroad companies in 50 years. Often the small improvements that they have made resulted from pressure from the states and not from their own initiative.

It is past time for the states and federal government to take the necessary action to improve safety at highway-railway grade crossings. The states and federal government must address themselves to this great need, for leadership will not be found in the railroad industry. The accidents and deaths occurring at highway-railway grade crossings should and can be reduced. However, the present warning systems will not improve the unsafe motoring conditions.

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