Effectiveness of Symbols for Lane Control Signals

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A need was indicated for improved signals for control of individual lanes on freeways and bridges in cases where accidents, maintenance, or unbalanced flow requires closing or reversing of a lane. Five criteria for more satisfactory signals than are now available for such use included (a) positive indication without false direction in malfunctioning, (b) distinctive appearance, (c) visibility and legibility, (d) ready understanding by most motorists, and (e) economic feasibility in the field. A series of different symbols was considered by the Michigan Highway Department from which the "red X" and "green-arrow-up" were thought to fulfill qualifications a, b, c, and e, and to be most promising for qualification d.

To test the readiness of understandability by the majority of motorists, research was carried out in two parts. Part 1 was an engineering psychology approach, which measured the types of meaning most commonly associated with six different possible symbols. To reverse or clear a lane, the desired motorist interpretation would not be "stop," but would be "do not drive in this lane" or "move into another lane." A total of 253 graduate and undergraduate students viewed signal presentations by means of colored slides showing the signals as if in place on the Mackinac Bridge and gave a total of about 4,200 reactions to the critical signal. Part 1 was a laboratory study and Part 2 a check of actual motorist reaction to the most effective signals when installed on the bridge.

Three experiments in Part 1 showed a consistent advantage for the "red X" as most often associated with the desired interpretation and least often with the undesired "stop." This advantage was most marked in the first experiment, where some indication of possible meanings of the signals was given. The standard red bullseyes, on the other hand, showed consistently a lesser proportion of the desired response and the largest proportion of "stop" responses. The latter would be undesirable where a lane is being reversed or cleared in order to get tow trucks or ambulances to a broken-down vehicle or to an accident. The laboratory study, therefore, confirmed the hypothesis that for most motorists the "red X" possessed advantageous natural associations with the desired meanings.

Part 2 consisted of checks of actual effects on bridge traffic of the "red X" and "green-arrow-up." A simple experimental setup employed a light wooden barrier and red flag in the right-hand lane beyond the signals. The red X was turned on for this lane during every alternate 5-min period. Comparisons of the point at which the weave was started showed that motorists were responding to the red X signal.

Thus, the "red X" and "green-arrow-up" not only showed the advantage of natural association with a desired meaning as shown in the laboratory, but also produced the desired motorist reaction in actual traffic.

●THE NEED for a satisfactory, clear and effective set of lane control signals has been pointed out by Gervais (1). On multi-lane facilities where it may be necessary or desirable to clear or reverse a lane to bring in a tow car or to accommodate unbalanced traffic flow in different directions the need is greatest. It was pointed out that the signals must satisfy five requirements, as described in Part 3.

To carry out these purposes, lane control signals were developed consisting of a red X and a green arrow pointing upward, together with speed indications. Prototypes were erected and viewed on full scale installation by the Michigan Highway Department on an experimental installation on the University campus.

It was hypothesized that they would satisfy requirement 4; that is that they would be readily understood by the motorist, even it a stranger to the signal system. However, it was desirable to evaluate experimentally this question. To do this a two-part study was undertaken. Part 1 describes a laboratory study of the psychological effectiveness of symbols in terms most naturally associated with the desired driver behavior. Part 2 reports a check under actual traffic conditions of the selected signals in use on the Mackinac Straits bridge described in Part 3.

PART 1—LABORATORY STUDY OF SYMBOL EFFECTIVENESS

Engineering Psychology Approach

Engineering psychology studies in related fields such as design of aviation instrument panel displays have shown experimentally that certain natural associations exist for the majority of people which tend to make some displays more effective than others. If certain types of symbols or controls lead the majority of a group of people toward more accurate or safer action, it is important that this be known and that designs be planned accordingly.

The standard red "stop" signal or "bullseye" when used for lane control may be ambiguous and may cause drivers to stop and clog a lane when it is necessary to clear the lane. To facilitate towing off a disabled vehicle or getting ambulances to an accident, stopping in the land under control would not be the desired driver behavior. The hypothesis was that certain other symbols might be more naturally associated with the "do not use this lane" idea when closing or reversing a lane on a bridge or freeway than the standard red bullseye.

The international symbol using a red arrow with a slash indicating a negative might be one such additional symbol. However, this is not yet familiar to most U.S. drivers and may have poorer legibility. A red X, on the other hand, was proposed as both more legible and probably indicating the general negative or "do not travel" association for the majority of people. In addition, red-arrows-up, red-arrows-down and a horizontal red bar and vertical green bar were suggested as worthy of try-out. Accordingly, the hypothesis that certain of these would show a more natural association to the desired prohibition of travel in a given lane was put to the test by psychological laboratory methods.

Experimental Method

Three different experiments were run using groups of subjects in undergraduate and graduate university classes. The procedure was similar for each of the three except that different amounts of information concerning the possible meaning of the signals were given. In this way not only a measure of ambiguity of the signals and of their association with the desired action but also a suggestion of the possible importance of a preceding informative sign were obtained. The procedure for the first group will be described and deviations from this procedure will be indicated for the second and third experiments.

A total of 253 different subjects in graduate and undergraduate classes gave a total of about 4,200 reactions to sets of colored slides depicting various combinations of the experimental signals on a sign truss on the Mackinac Bridge.[1]

[1] Prepared through the cooperation of the Michigan State University Audio-Visual Center from photographs of the bridge, a truss, and the experimental symbols.

First Experiment—Alternatives Indicated

This group was given an indication of possible meanings of the symbols in the form of six possible driver actions for each lane as follows: (a) stop in this lane; (b) go in this lane; (c) do not drive in lane; (d) slow in lane; (e) warning in lane; and (f) drive indicated speed in lane.

Procedure.— Two classes of students in a course in Industrial Psychology were used as subjects. One class had 58 students and the other 38. Slides using the different symbols were presented, and subjects recorded their interpretation of the meaning of the symbols for each lane. Instructions were given as follows:

> We are studying how drivers interpret signs and signals. You are to pretend you are driving on the Mackinac Bridge, and are to be confronted with various types of signs and signals. You are to write down your interpretation of what they mean.

At this point a color slide was shown on the screen, and instructions continued as follows:

> Here we have the Mackinac Bridge, and a truss with no signs or signals mounted on it. Because of traffic conditions to be expected on the bridge, and because traffic lanes may be blocked by accidents, traffic in either direction may be directed to any lane. The median divider in the center of the pavement is a low rounded curb which can be crossed easily.
>
> For each slide you are shown, you are to write on your answer sheet the letter corresponding to what you think the signals mean for each lane. Additional comments are to be written in the space provided.

Each student recorded an action for each lane on this answer sheet. These answers formed the data of the experiment.

Examples of the signals used in the experiment are shown in the Appendix. A different order of presentation of various signal combinations was used for the two groups of subjects. The more important combinations appeared twice in each case. For each group, the first set was composed of standard traffic signals with the right two lanes green and the left two red, to give a "mental" set like that of a driver who had passed through a town using standard traffic signals. The standard signals also occurred later with a different combination of lanes, so that results could be checked. The 5-lane combinations (green in the right hand lanes 1 and 2, 2 and 3, 1 only, 3 only, and 1, 2, and 3) were presented in random order.

Second Experiment—Completely Free Responses

In this experiment a second group of subjects was shown the colored slides presenting different combinations of signals on the Mackinac Bridge, as before, but without any multiple choice answers. It was desired to see whether these alternative responses acted as information concerning the meaning of the signals. If so, completely free responses on the part of the subjects might be expected to give somewhat different results.

Procedure. — The subjects were given blank sheets of paper on which they marked four columns corresponding to the four lanes. They were instructed to write for each slide the meaning of the signal over each lane by a word, phrase, or sentence indicating what they thought the signals indicated. Otherwise, the procedure was the same as for the previous experiment. Two groups totaling 48 subjects participated.

The written-in responses were classified into categories like the responses of the previous study. The number in each category gave a response score for each signal.

Third Experiment—Free Response on Action in Designated Lane

The responses of subjects in the second experiment were in some cases rather indefinite and difficult to classify and many omissions occurred. Therefore, a third group of subjects was shown the experimental slides and asked what they would do if they were driving in a certain lane and responding to the signals shown. This set of instructions was designed to put the subjects more into a driving frame of mind.

Procedure. — The third study differed from the previous ones in these ways: (1) pairs of slides presented (a) a certain combination of signals followed by (b) the same signals but with a changed indication in one lane; (2) the subjects were asked to state what they would do if they were driving in a certain lane; and (3) the designated (lane 1 or 2) was the one in which the signal changed in the second slide of each pair.

The series balanced the order of presentation of the different symbols and the use of lanes 1 and 2 as the designated lane. One group of 48 subjects was given one order of presentation and a second group of 61 (in two different classes) was given another order to achieve this balancing.

Analysis of Data

Statistical significance tests were made to determine whether differences in responses to the signals were sufficiently reliable to use as a basis for conclusions. The common chi-square tests were not applicable to these data, so the sign test (2) was used as follows: for every observer, the percent of "don't drive" responses given for the red X was compared to the percent for each other signal. Each observer for whom the red X percent was better was scored a plus in the sign test, and each observer for whom the other signal was better was scored a minus. The same procedure was repeated for the "stop" responses. From these, the probability of obtaining such differences by chance was computed.

Results

Results from the laboratory presentations are shown in Figures 1, 2 and 3. The red X was either highest in "don't drive in this lane" or lowest in "stop" responses or both except for Experiment 2. Here the pattern was somewhat similar but responses

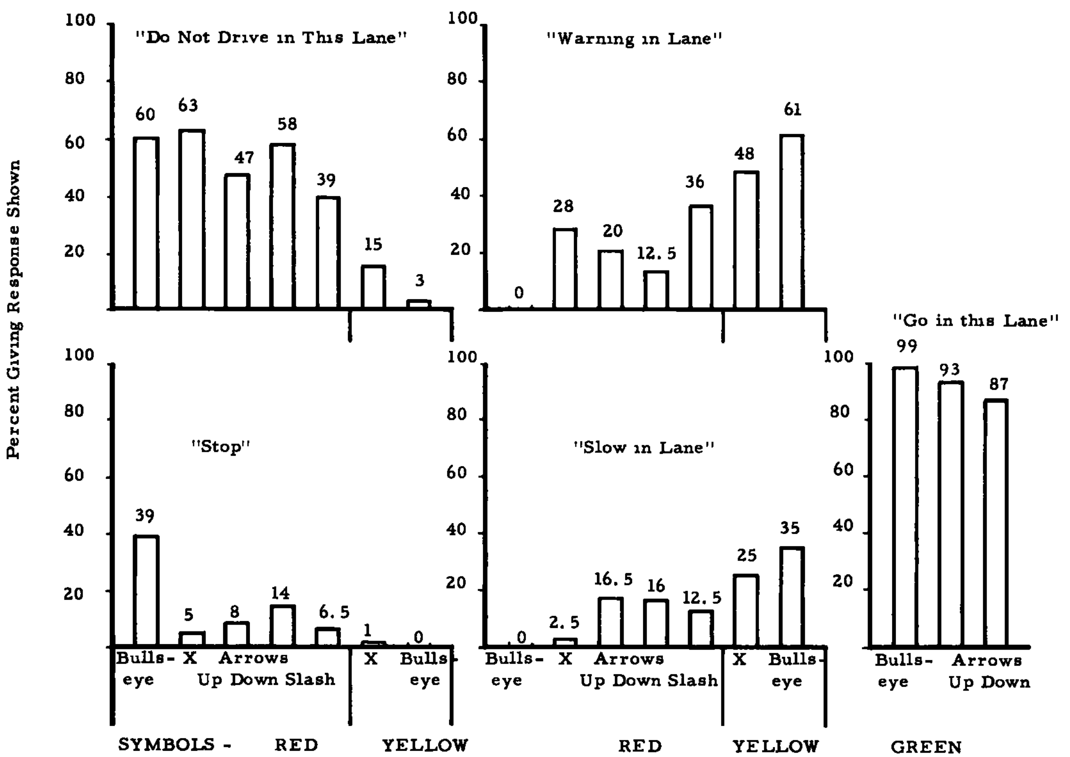

Figure 1. Interpretations of lane control symbols— laboratory experiment 1.

by the group were less consistent and complete as noted above. Note that "go" was the almost unanimous interpretation of all green symbols. Therefore, one must be chosen which differentiates between the "everybody go" and "this lane go" ideas.

The statistical analysis of results for Experiment 1 showed that in percent of "don't drive" responses, the red X was significantly better than the up-arrow, the slashed-arrow, and the amber signals. In the percent of "stop" responses, the red X was significantly better than the red bullseye and the down-arrow. So, in terms of either the "don't drive" responses or the "stop" responses, the red X was superior to each of the other signals tested.

From the second experiment it was thought that although results were not essentially different from results of the first experiment, however, differences between signals were not statistically reliable enough to permit definite conclusions.

From the third experiment results were again similar in direction to those of Experiment 1. The significance test, applied as previously, showed the red X significantly better than the red bullseye in terms of both "move over" and "stop" responses, and differences between the red X and the red bar were almost statistically significant. Other differences were not large enough to be statistically significant. The statistical test was applied to the results of all three experiments combined. For the percent of "don't drive" or "move over" responses, the red X was significantly better than the up-arrow, the slashed-arrow and the amber signals. In terms of "stop" responses, the red X was better than the red bullseye, the down-arrow, and the red bar. So, by one criterion or the other, the red X was significantly better than each of the other signals tested.

Discussion of Laboratory Results

The results of the three laboratory experiments together show that there was a consistent advantage accruing to the red X signal with the "slash arrow" and "arrow-up" coming next with the standard red bullseye ranking last in producing the desired reaction

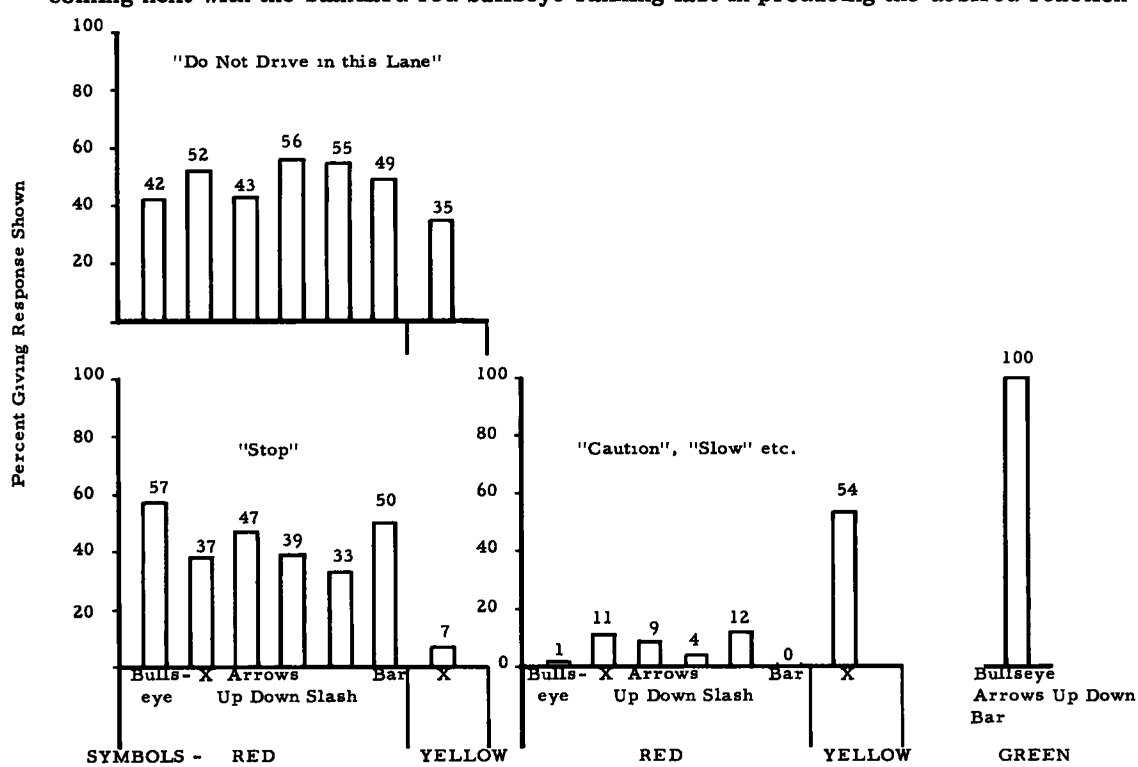

Figure 2. Interpretation of lane control symbols—laboratory experiment 2.

"do not drive in this lane" or "move into another lane." The reverse relationship was consistently shown for the undesired "stop" reaction.

The most clear-cut advantage was shown in the first experiment where some knowledge about the possible meaning of the different signal symbols was given by means of the alternate answers provided. The advantage was reduced or less consistent where no information at all about meaning of the signals was given (as in the second completely free answer case and in the third experiment).

Analysis of the comments and discussion with subjects revealed that they considered the slashed arrows very confusing. They considered the red arrows confusing also. To some subjects the red arrows downward clearly indicated "stop right here."

These results indicated (a) an advantage for the red X in association with the proper behavior when a lane is being closed or reversed and (b) the importance of giving the motorist minimum information on the purpose of signals (perhaps).

The differences ranged from 3 to 34 percent of responses. It is important that these

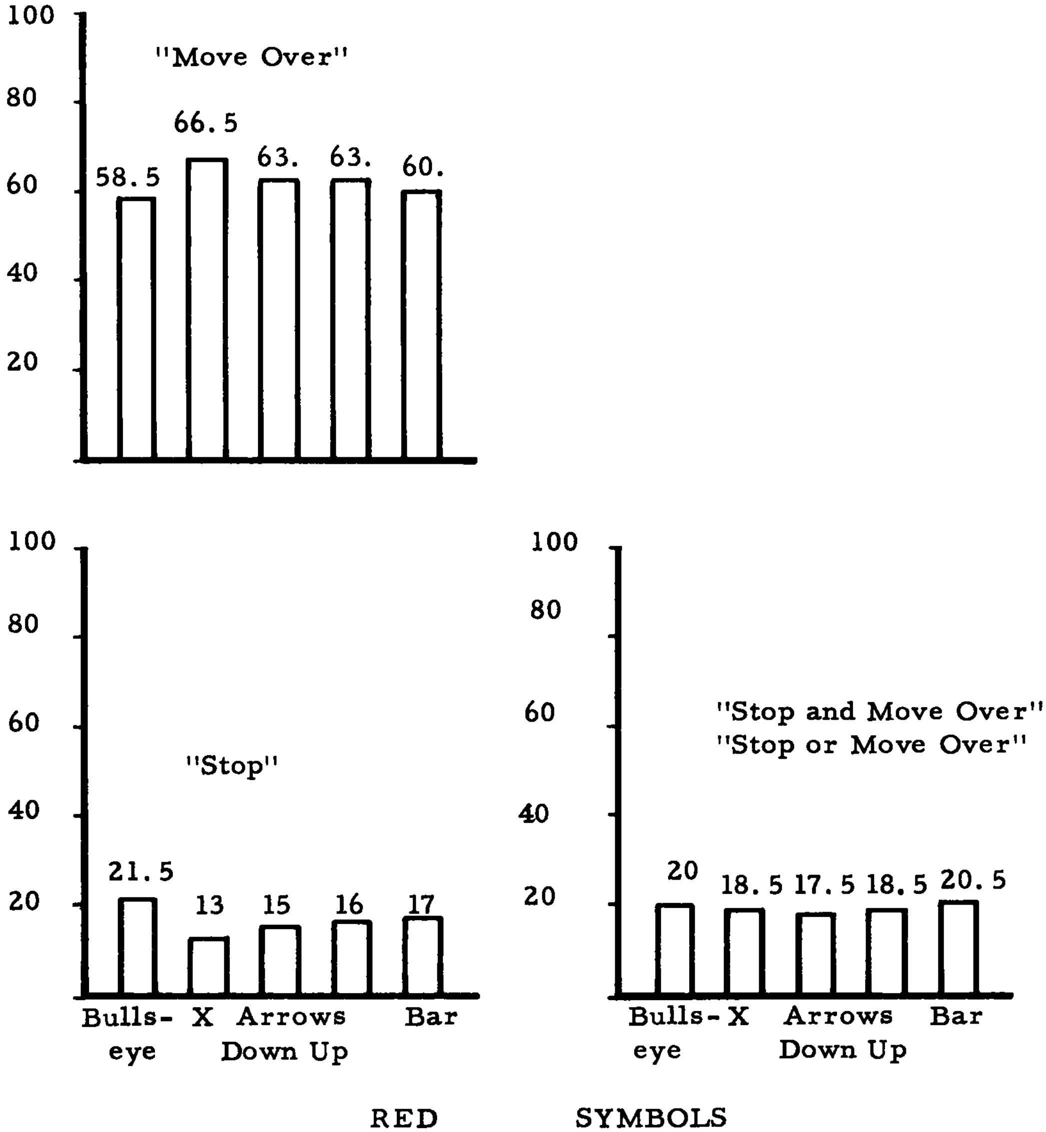

Figure 3. Interpretation of lane control symbols—laboratory experiment 3.

individuals were entirely unfamiliar with such signal symbols. General use of the red X can be expected to increase its advantage; that is, reduce the possible double meaning now given the red bullseye.

The "green-arrow-up" distinguishes between "everybody go" and "cars in this lane go" and also has certain possible consistency advantages if map symbol destination signs are used.

PART 2—EFFECTIVENESS OF LANE SIGNALS ON BRIDGE

Purpose

The purpose of this part of the study was to check in actual traffic the effectiveness of the lane signals indicated by the laboratory results. Individual lane control signals were installed on the Mackinac Bridge, as described in Part 3. Mounted over each lane were the red X shown to be advantageous in the laboratory study and the green-arrow-up.

It was not possible because of practical considerations to test all of the different symbols, but it was highly important to find out (a) to what extent drivers responded with the desired change of lane to the red X and (b) whether an advance information sign increased effectiveness.

Experimental Method. — A simple experimental situation was developed and records of driver-and-vehicle responses were made by visual observation and by photographic recording. A wooden barrier bearing a red flag and light enough to present little hazard if hit by a car was set up in the right hand, northbound lane 300 ft beyond the third signal bridge (located just north of the north bridge anchor). This set of signals was put on local control. During each alternate five min the red X was switched on over the right hand lane while the green arrow showed during intervening 5-min periods. Observers were stationed in a parked car on the concrete bridge anchor, a location where other cars were parked at the south end of the bridge in connection with painting operations at that end. The car and observers were relatively inconspicuous.

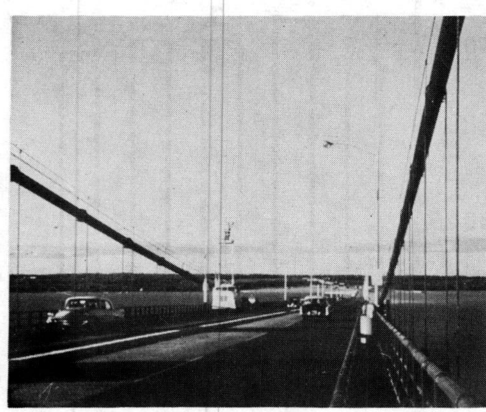

Figure 4. Tower truck under luminaire on southbound lane as seen by northbound drivers.

A tower truck was parked under a luminaire 750 ft south of the signal bridge and its tower extended as if for work on the luminaire. Time lapse photographs were made from a camera stationed on this tower. Figures 4 and 5 show the setup on the bridge.

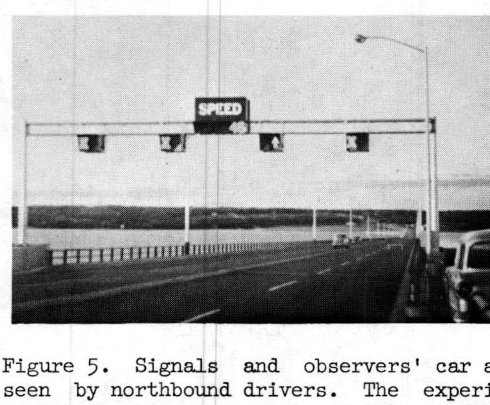

Figure 5. Signals and observers' car as seen by northbound drivers. The experimental barrier is just visible in the distance in right lane.

Aluminum markers were placed at 150-ft intervals on the bridge center strip opposite each light standard and these were used as scale points to assist the accuracy of visual observations. Two observers made independent estimates of the point at which the left wheel of approaching vehicles crossed the lane dividing line as vehicles started to weave from the right lane to avoid the barricade. The barricade with its red flag was sufficiently visible for safety but was not conspicuous for any great distance.

Traffic on the bridge was traveling at from 15 to 40 mph, for the most part, even though the speed limit was set continuously at 45 mph on the signal bridge. This low speed resulted from the desire of drivers and passengers to view the scenery and is a consistent characteristic of the traffic on this bridge.

Experimental Design

The experimental design was based on the hypothesis that if the normal average turn-out point for the barrier (green-arrow showing) was beyond the signal bridge, any effect of the red X on driving behavior should produce a weave at an earlier point as the car approached. Second, any variations in traffic would be equalized by displaying the red X in alternate 5-min periods. Comparisons could then be made in the analysis between these periods and the intervening 5-min periods in which the green-arrow-up was showing.

Finally, it as planned to make observations on two weekends. The first would be without any explanatory sign on the bridge approach and the second would be after installation of an explanatory sign. Statistical comparisons of the relative effectiveness of the red X on these two weekends would then be expected to show whether or not the explanatory sign was of importance, as suggested by the laboratory results. Unfortunately, weather conditions made this last comparison somewhat less than conclusive.

Statistical Analysis

The visual estimates of starting point of each weave were recorded in feet from a zero point 300 ft south of the sign bridge as estimated from the 150-ft markers. These observations were analyzed to compare the average starting point for each half-hour interval of the respective time periods when the red X and the green-arrow-up were showing. In addition, the statistical significance of the differences between averages was tested to estimate the probability of their occurrence by chance.

Results

Analysis of the photographic records provided spot checks of the visual estimates. (The time lapse photographs were analyzed by the method reported by Forbes and Fairman (3) and modified by a further grid derivation for a 4-in. telephoto lens employed on the bridge.) Also, the visual estimates proved to be of high statistical reliability and are believed to be satisfactory for this study. The correlation between the individual estimates of the two observers on the same group of cars was 0.949. A reliability coefficient of this magnitude is ordinarily indicative of highly consistent and reliable estimates.

Analysis of the estimates and comparison between red X and green-arrow-up for each half-hour showed statistically reliable effects of the red X in the hypothesized direction. The observation averages are shown in Figure 6. The first set was made on October 18 and 19, and the second set on November 8 and 9. The figure shows that the weaves were longer for both the red X and the green-arrow-up on the second weekend. In both sets of observations the average starting point was earlier with the red X showing.

Differences between the red X and green arrow means for each of the half-hour periods were significant at the 0.01 level, with one exception for the first weekend. For the second weekend, the differences recorded between 8:30 and 10:30 were significant at $P = 0.05$ or less, but those for earlier and later half hours were not statisticaly significant. This was probably due to fewness of observations since the difference was statistically significant when all hours were combined.

Interpretation of Results

The observations from both weekends showed that in actual traffic the motorists responded to the red X signal by starting their weave definitely earlier. Even without the explanatory sign at the bridge approach on the first weekend, the red X signal was effective. It was even more effective on the second weekend.

The results for the second weekend showed a similar effect, but the starting point of the weave was earlier for both the red X and the green-arrow-up periods. It is probable that this was due to the weather on this weekend, which was overcast and rainy. A shift of operating behavior is characteristic of rainy and slippery weather and is well known in many other types of traffic observations and surveys. Also, early and late comparisons were not statistically reliable as noted above. Since both weather and the sign on the bridge approach may have played a part, it was impossible to separate out the possible effect of information on the sign explaining the red X symbol.

Figure 6 shows that on the first weekend the red X was much more effective in the earliest and latest half-hour periods. During the middle of the day it had less effect in producing an early weave. This was probably the effect of "sun phantom" in the bright sunshine on this first weekend. Reflection of the sun from the green plastic was especially noticeable, and at a distance might give drivers the impression that the green arrow was showing even when the red X was being displayed. This was because of the greater brightness of the green reflection and a triangular shape caused by the sun vizor shadow. Steps are being taken to remedy this condition.

The figure indicates less of this change in effectiveness in midday the second weekend, which is consistent with the fact that observations were taken under overcast and rainy conditions with very little bright sunshine to be reflected from the green plastic.

PART 3—MACKINAC BRIDGE SIGNALS

Lane control can serve a very important purpose in obtaining efficient and safe bridge or expressway operation and directional control of traffic lanes. If a lane of an expressway is closed to the movement of traffic due to an accident, maintenance, construction or traffic stagnation, it is important to give the driver immediate knowledge of the condition at a sufficient distance down the roadway so he can alter his travel path. In the case of reversing lanes of a multilane bridge or expressway, the need of a lane

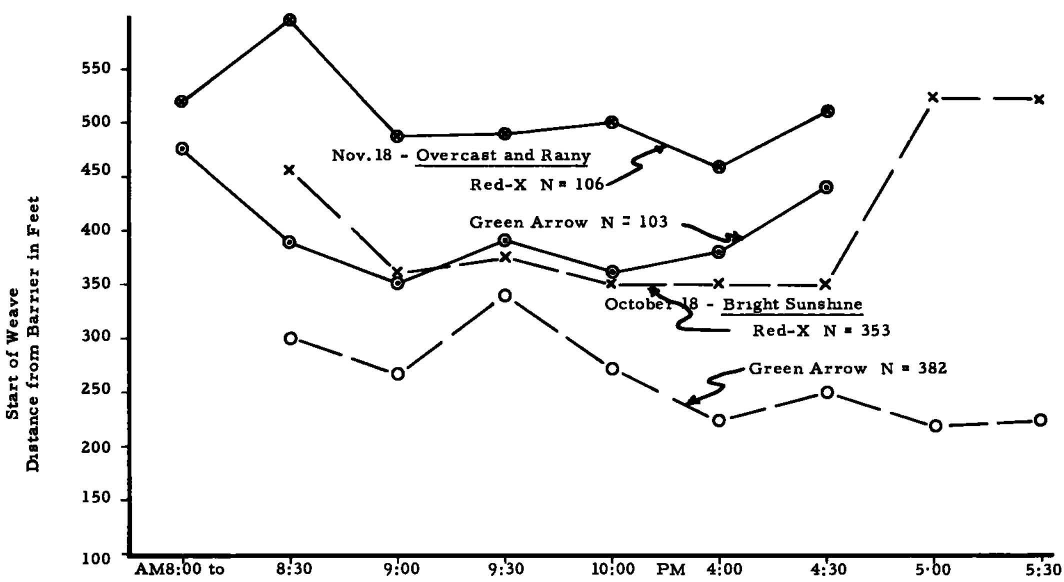

Figure 6. Effect of red X signal on start of weave. Averages for red X and green arrow displayed during alternate 5-min periods. Red X signal gave earlier weave. Less effective in midday probably due to green sun phantom on sunny week-end. All weaves longer on rainy week-end but red X still increased average distance.

control signal system to properly inform drivers of lane assignment to their direction of travel is quite obvious.

The problem of conveying information to the driver regarding lane and speed control is filled with complications and needs very careful study. Variable speed control is the simplest of the two and the biggest problem is the determination of the number of different speeds which may be needed for a certain roadway. The less speed values used, the simpler the construction of the speed sign and the control. There should be enough speed values to satisfy the number of conditions which require a definite speed band. In the initial tests three speeds were decided on which would be indicative of normal driving speed, heavy traffic and emergency speed. The problem of determining the need of different speeds for individual lanes was dismissed for the initial tests due to several considerations which will be discussed in a later publication.

The problem of conveying information to a driver on whether he may drive on a lane or keep off has complications when it is appreciated that each lane must give a message independent of that on an adjacent lane. This means there are as many messages as there are lanes for each control point. If a legend were used to convey this information, the simplest possible would be one which reads either "use lane" or "keep off lane." When it is considered that legend letter sizes on high-speed roadways should be approximately 16 in. vertical height with corresponding horizontal dimensions in order to be effective, the result would be a very sizeable sign. Since a variable-legend sign would by necessity be electrical, the problem is increased.

These considerations made it very desirable to consider signals which would have faces displaying symbols that would convey the proper lane information but be simple in construction. The determination of the proper lane symbol signals is set as one of the first objectives.

The signals which would be used for lane control would have to satisfy the following conditions:

1. The signals will be positive in their action and malfunctioning will not give false directions to the motorist.
2. The signals in relation to one another will be distinctive in their appearance.
3. They will be clearly visible and legible under the greatest range of conditions to the largest number of motorists.
4. Their message will be readily understood by the motorist—even if a stranger to the signal system.
5. The cost of the signal system will be economically feasible for adaptation in the field.

Under the first requirement, a two-way signal is practically dictated since one signal gives the motorist the permission to use a lane while the opposite signal denies him the privilege. This system is practically fool-proof since the only way a motorist could receive a false signal by mechanical failure would be for one signal to burn out while the counter signal was receiving a false electrical feed. Good circuit design would render such an occurrence practically nil.

The second condition will be best satisfied if the two signals have distinctive shape, color and mounting position. Since there is a restriction in the shape of the signal due to manufacturing difficulties, this shape can be acquired by a distinctive symbol legend on each signal which minimizes any possibility of confusion with one another. A further condition which must be satisfied in this respect is that the symbols chosen do not conflict with established symbols used for purposes other than lane control. In order to obtain distinctive contrast in the two signals by color, one must be chosen in the so-called "hot" color range which is the yellow to red and the other in the "cool" color range which is the violet to green. The "hot" color should be the prohibitory signal because of common usage and better bad weather visibility. Improper action on the driver's part while it is being displayed could lead him to an accident. Misunderstanding the signal permitting lane use would merely restrict his use of a lane. Mounting position can be utilized to distinguish the two signals by always mounting the prohibitory signal on the left side of the action signal.

The visibility of the signals to the motorist can best be acquired by their size, intensity of illumination and distinctiveness of symbol. The fact that a bigger signal has greater visibility is axiomatic and needs little discussion. The combination of intensity and distinctiveness of legend does have complications and must be carefully treated. The greatest difference of appearance in the two chosen symbols will be obtained if one signal has a distinctive vertical shape while the other is basically horizontal. The intensity of the light must be balanced so that adequate visibility is given the signal in the sunlight while detrimental visual spreading is not caused during darkness.

Part 2 of the study logically called for the field evaluation of the signals. The recently completed Mackinac Bridge offered a splendid opportunity to study the effectiveness of the signals under practical operating conditions. The Mackinac Bridge is a 4-lane bridge spanning an open water area approximately 5 mi in length. It consists of a combination of causeway, span truss sections and a huge suspension span in the center which is the longest ever constructed from anchorage to anchorage. There are four aluminum truss spans mounted over the roadway on the bridge. The maximum distance between spans is approximately 8, 500 ft while the shortest distance is 3, 600 ft. Availability of mounting positions for the signal spans made this variation in spacing necessary, but the roadways and type of bridge construction along these lengths were uniform, which gives some justification for the arrangement. For study purposes this gives a further advantage since it permits an evaluation of the maximum distance permissible between control points.

A span was placed at the Mackinac City side of the bridge in which the signals faced only the direction of traffic approaching the bridge from the south. Traffic leaving the bridge was departing from the control area and did not require signalization. Spans in which signals faced both directions of travel were placed at both of the concrete anchor piers of the suspension bridge and at the beginning of the trestle section of the bridge located 3, 600 ft north of the north anchor pier. There is a distance of 3, 600 ft between this latter signal span and the beginning of the bridge causeway to the north. It is not necessary to have a lane control signal span north of the causeway section since traffic moving south must enter the bridge through the toll gates. They can be moved into their

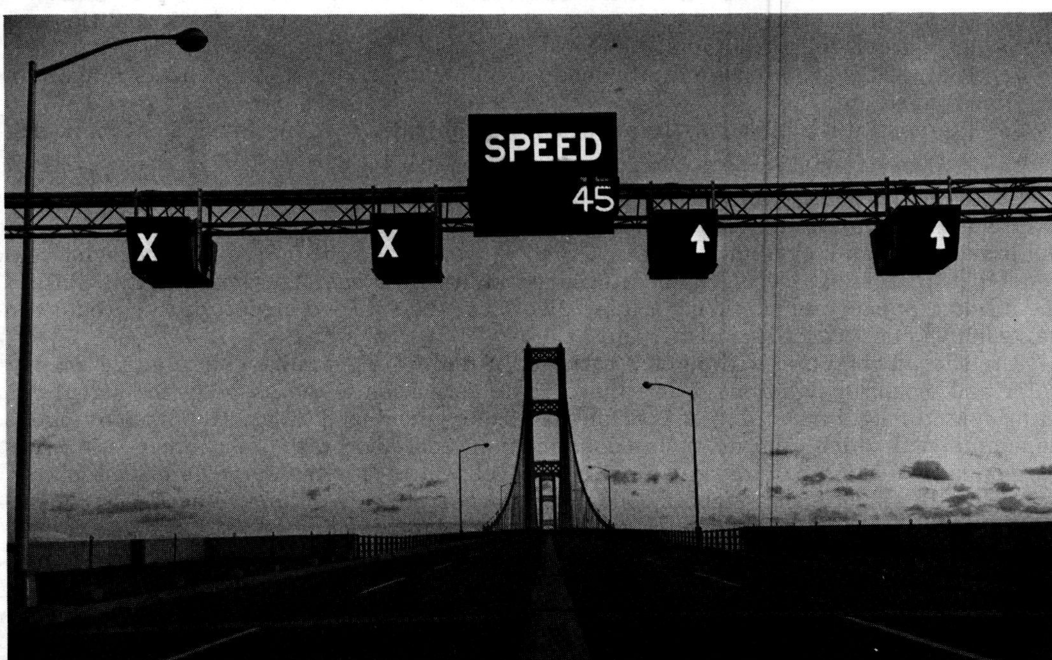

Figure 7. View of signals on Mackinac Bridge showing design of red X, green arrow and speed signals.

proper lanes by traffic cones set south of the toll gates. Speed control is still needed, however, so a variable speed control sign facing southbound traffic is erected at the roadside just south of the toll gate area.

The lane control signals employed at the bridge (Fig. 7) are blank-out signals with high-intensity neon tubing providing internal illumination. The use of neon tubing is required by the size of the signals (17 by 28 in.) and the need of high-intensity lighting for the purpose of providing an effective blank-out signal. One pair of signals is mounted over each lane of the roadway. This makes a total of eight lane signals facing each direction. Inasmuch as there are seven signalized directions, there is a total of 56 signals.

The speed control signals are mounted over the center of each lane control signal span. Three different speed messages were chosen for the Mackinac Bridge which are "15, 30, and 45." The 45 is the normal operating speed while the 30 is used for heavy traffic and semi-emergency conditions. The 15 is utilized for emergency conditions.

The 3-speed messages are grouped horizontally with the lowest speed to the right and the highest to the left. The word "speed" in 16-in. molded plastic letters internally illuminated is placed over the 3-speed messages. The sign reads either "Speed-45" or one of the other messages at any one time. This has already proven effective and there has been no misunderstanding as to the speed limit being in miles per hour. Since there are seven overhead speed sign units and one roadside installation, there are 24 different speed signals. Other details of the signals and their control will be described elsewhere.

Importance for Expressway as Well as Bridge Operation

The experiments reported showed that the red X symbol has certain inherent advantages for use in lane control signals. It was more frequently associated with the "do not use this lane" idea and less often associated with the "stop here" idea. The signals using the red X and the green-arrow-up were shown to be effective in actual traffic in influencing driver behavior.

The differences in driver behavior which were induced and the percentage of advantage in the natural association with the desired driver interpretation resulted when the red X was completely unfamiliar to the people responding. Greater familiarity from use of the red X symbol with a brief explanatory sign on more highway facilities should greatly increase the advantage gained by the use of this signal. Furthermore, restricting the use of the red bullseye to the "stop here" idea would make more definite and clear-cut the meanings intended for both signals. It is, therefore, suggested that use of the red X wherever the meaning "don't travel in this lane" is intended should be given further consideration and experimental usage.

The signal combination tested and in use on the Mackinac Bridge would also be of value in the operation of freeways. In fact, the original consideration of such signals included both freeway and bridge use wherever with multiple lanes, the possibility of reversing lanes, or the need for closing and clearing one lane was involved. The results reported here indicate the suitability of these signals for both types of lane control operation. The distance values furnish at least an initial guide for experimental location of sign and signal bridges on freeways.

An additional problem has also been considered for the freeway operation case which is not present in the bridge requirements. This is destination sign design based on the same engineering psychology approach which has been used for the lane signal design. Here certain other variables enter such as the need for identifying the interchange, directions of connecting routes and the like. The experimental approach developed in this study modified to include the additional variables can evaluate word and symbol combinations for best effectiveness in a somewhat similar way.

ACKNOWLEDGMENTS

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Appendix

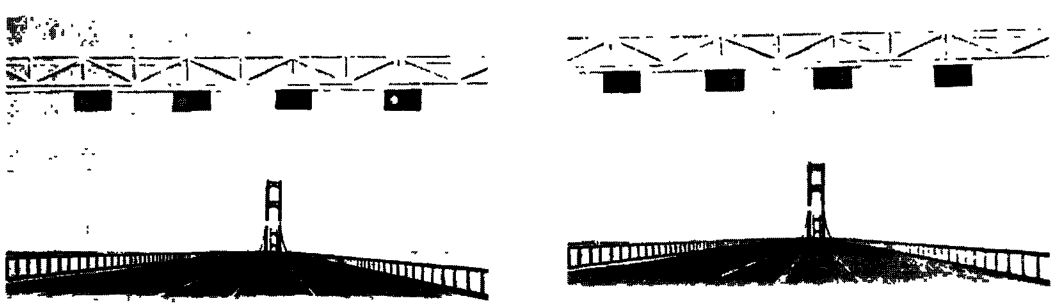

Figure 8. Examples of laboratory presentations from colored slides used in experiment. Pictorial representation of bridge and different symbols used to test associated meaning of symbols. See Figure 7 for actual signal designs. Left—bullseye signals—red over lanes 1, 3 and 4, green over lane 2. Right—red x over lanes 1 and 4, green arrow over lanes 2 and 3.

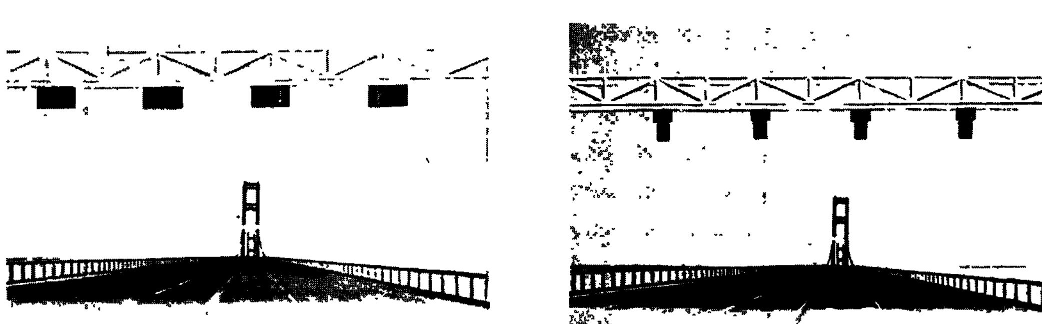

Figure 9. Other examples of laboratory presentations from colored slides used in experiment. Pictorial representation of bridge and different symbols used to test associated meaning of symbols. See Figure 7 for actual signal designs. Left—red slash-arrow and green arrow. Right—red bar over lanes 1, 3 and 4, green bar, lane 2.

TABLE 1

STATISTICAL SIGNIFICANCE LEVELS FOR INTERPRETATION OF LANE SIGNAL SYMBOLS—LABORATORY RESULTS—SIGN TEST ANALYSIS RED X VS OTHER SYMBOLS

	Experiment 1					
	"Don't Drive" Responses			"Stop" Responses		
Signal Symbols	N[1]	X[1]	α[2]	N	X	α
Red bullseye	71	35	0.500	57	50	< 0.001[3]
Red—arrow-up	71	49	0.001[3]	22	13	0.262
Red—arrow-down	66	35	0.356	28	20	0.019[3]
Slashed-arrow	62	51	<0.001	18	10	0.407
Amber-X	77	72	<0.001	10	1	0 999
Amber-bullseye	82	80	<0.001	11	1	0.999
	Experiment 2—Differences not Statistically Significant					
	Experiment 3					
	"Don't Drive" Responses			"Stop" Responses		
	N	X		N	X	
Red bullseye	45	31	0.009[3]	47	34	0.002[3]
Red—arrow-up	43	22	0.500	43	21	0.500
Red—arrow-down	41	22	0.378	43	24	0.271
Red-bar	41	26	0.059	44	28	0.049
	Combined Results Experiments 1, 2, 3					
	"Don't Drive" Responses			"Stop" Responses		
	N	X		N	X	
Red bullseye	124	71	0.064	114	91	<0.001[3]
Red—arrow-up	124	76	0.008[3]	75	41	0.245
Red—arrow-down	116	60	0.390	79	48	0.036
Red-bar	51	32	0.047	54	35	0.021[3]
Slashed-arrow	71	54	<0.001[3]	26	9	0.915

[1] N = number of subjects less ties: X = number of subjects for which Red X was better.
[2] α = one tailed significance level (probability of chance occurrence).
[3] Red X significantly better at 0.05 level or better, two-tailed test.

TABLE 2

EFFECT OF RED X SIGNAL ON START OF WEAVE-SUNSHINE-NO SIGN STATISTICAL SIGNIFICANCE OF DIFFERENCE OF MEAN STARTING POINTS VISUAL OBSERVATIONS OCTOBER 18 AND 19, 1958

	Zero Point 300 ft Ahead of Signals					
Time	$M_{\uparrow}$	M_X	Diff.	t	df	P
8:30- 9:00	295.0	101.6	193.4	4.10	59	< 0.01[1]
9:00- 9:30	328.1	205.0	123.1	4.31	120	< 0.01[1]
9:30-10:00	260.1	195.8	64.3	2.03	157	< 0.05[1]
10:00-10:30	326.1	210.5	115.6	4.17	59	<0.01[1]
4:00- 4:30	373.8	202.8	171.0	5 51	55	<0.01[1]
4:30- 5:00	357.0	202.4	154.6	5.74	133	<0.01[1]
5:00- 5:30	243.4	32.4	211.0	6.97	100	<0.01[1]
5:30- 6:00	378.8	33.0	345.8	6.92	36	<0.01[1]
Green arrow Sat. morn. and Sun. morn.	297.6	291.2	6.4	0.26	190	>0.05
Red X Sat. morn. and Sun. morn.	202.9	172.2	30.7	1.15	209	>0.05
X vs Arrow Both days all hours	310.	160.	150.	11.54	733	<0.01[1]

[1] = Significance at 0.05 level or better.

TABLE 3

EFFECT OF RED X SIGNAL ON START OF WEAVE-RAINY-SIGN ON BRIDGE APPROACH STATISTICAL SIGNIFICANCE OF DIFFERENCE OF MEAN STARTING POINTS VISUAL OBSERVATIONS NOVEMBER 8 AND 9, 1958

	Zero Point 300 ft Ahead of Signals					
Time	$M_{\uparrow}$	M_X	Diff.	t	df	P
8:00- 8:30	125.0	85.7	39.3	0.80	15	>0.05
8:30- 9:00	268.8	-23.3	292.1	5.97	29	< 0.01[1]
9:00- 9:30	240.0	118.0	122.0	2.72	43	<0.01[1]
9:30-10:00	209.2	112.5	96.7	2.09	56	<0.05[1]
10:00-10:30	243.8	100.0	143.8	3.32	57	<0.01[1]
4:00- 4:30	220.8	138.9	82.9	1.77	40	>0.05
4:30- 5:00	164.6	93.8	70.8	0.84	18	>0.05
Green arrow Sat. morn. and Sun. morn.	219.6	216.3	3.3	0.10	101	>0.05
Red X Sat. morn. and Sun. morn.	97.1	86.1	11.0	0.34	104	>0.05
X vs arrow Both days all hours	219.5	96.2	123.3	6.35	270	<0.001[1]

[1] Significance at 0.05 or better.