IN-VEHICLE DRIVER AID AT TRAFFIC SIGNALS

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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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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.

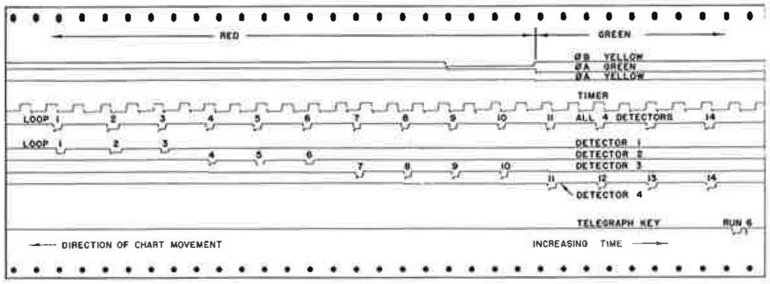

Figure 3. Display panel positioned on top of dashboard of test vehicles.

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

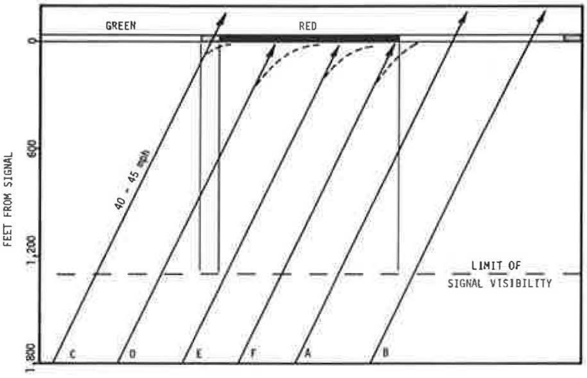

Figure 5. Analysis of operation recorder chart.

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

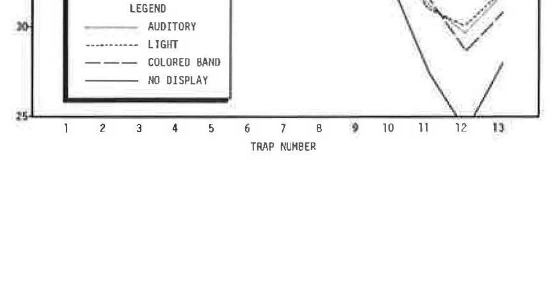

Table 1. Summary of results.

Travel Characteristic (avg)	Signal Approach Condition	Display: Auditory	Light	Colored Band	None	Best Versus None	Smoother or Safer[a]
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.

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