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Number 292

Drivers and Driving

6 Reports

Subject Area

52 Road User Characteristics

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Foreword

The investigations that led to the six papers comprising this RECORD are concerned with learning more about drivers and driving tasks. Although their common thread is drivers, the papers' subjects are diverse, including studies of wrong-way movements, passing, seeing, and sensing, as well as driver reeducation. The RECORD should be of interest and value to traffic engineers, human factors specialists, and others concerned with the driver and the driving task.

Three researchers at Ohio State University prescribed three levels of visual workload for test subjects under two different actual driving conditions. An eye camera was used to record drivers' visual search and scan patterns, and a lessening of visual effort was noted for drivers in a car-following situation when compared to open driving. Possible visual aids for decreasing visual workload are discussed.

The second paper reports observations of passing behavior of motorists on a rural two-lane highway for day and night conditions. The passing situations were forced on unsuspecting motorists by operation of an observer-operated lead vehicle. The author found significant differences between opposing vehicle distances accepted by passers during day and night conditions, and concludes that a hazardous pass is more likely to be the result of choice rather than of a distance-judgment error.

An examination of biographical and environmental data for wrong-way drivers on California freeways and expressways produces a picture of the typical offender. Most wrong-way driving occurs at night and on weekends during light traffic periods in good weather by motorists who regularly use the highway. The typical motorist is under 50 years of age, is a had-been-drinking male, and has considerable driving experience. He is generally a blue-collar worker, has good vision, and is not handicapped. He is, however, involved in more accidents, driving violations, and felony convictions than the average motorist. The emphasis here is on preventive traffic engineering tools and techniques, rather than on the driver. Several measures were tested and proved effective in reducing both accidents and incidents. Two discussions by highly respected traffic engineers and a closure by the author add significantly to this presentation.

University of Kentucky researchers used the "candid camera" technique to record actual good and bad local driving practices for showing locally on television. The reeducation effort was tested for effectiveness by two methods, and the authors conclude that the technique is effective in reducing accidents and driver errors.

In the next paper, the researchers tried to better define driver overtaking and passing behavior on rural two-lane highways by determining the singular and combined effects of impedance distance, impedance speed, passing sight distance, and traffic volume on acceptance of passing opportunities. They found that passing sight distance is the prevalent variable influencing the decision to pass.

The final paper compares the effect of varying sensory input on the appreciation of traveled velocity. A technique was developed to present frontal and peripheral cues without the effects of acceleration, and conclusions were drawn regarding the accuracies with which speeds could be estimated.

Contents

Drivers' Eye Movements and Visual Workload

R. R. MOURANT, T. H. ROCKWELL, and N. J. RACKOFF, Systems Research Group, Ohio State University

An eye-marker camera was used to record drivers' visual search and scan patterns under three levels of route familiarity (mediated by instructions) and two driving conditions (open driving and steady-state car following). The drivers drove on an expressway route for which they had memorized a set of directions. They were instructed on Trial 1 to read all road signs as a driver who is unfamiliar with the route must do; on Trial 2 to read only those signs necessary; and on Trial 3 to try not to read any signs as the driver who is very familiar with the route does. The results showed that for open driving the visual patterns shifted to the left and down and showed more compactness as a function of trials. In addition, the percent of time spent viewing road signs and the saccadic travel distance to fixations on other traffic, road and lane markers, and bridges and road signs decreased as the driver became more familiar with the route. For car following, the increase in compactness of the visual pattern over trials was pronounced but there was no change in the center of location of the visual pattern. Compared with open driving, the travel distances for car following were greater when looking ahead and at bridges, road signs, and other vehicles. However, drivers in the car-following condition spent less time reading road signs, indicating that they used the lead car as an aid for route guidance. Possible visual aids for decreasing the driver's visual workload under today's driving conditions are discussed.

A POSSIBLE WAY to relate visual workload to the driving task is to record eye movements the first time a driver is traveling on a particular route, and then again when he has become very familiar with the route. Differences between these two eye-movement records would then be reflective of changes in visual workload caused by a driver's increased familarity with his route.

This type of information has particular relevance for highway designers. On a well-designed expressway, the visual workload of the unfamiliar driver should be as close to that of the familiar driver as possible. It is rather apparent that when an Interstate highway goes through almost any large city, the unfamiliar driver is at a distinct disadvantage. Many out-of-state drivers make sudden maneuvers and stops as they attempt to find the correct route. Connolly (1) has also reported that many of today's traffic conditions overload a driver's psychological sensing ability. The present study will detail changes in drivers' visual sampling patterns as the drivers go from an overloaded visual workload condition (Trial 1) to a condition that has moderate visual workload (Trial 3). In addition, analysis of the eye-movement data will also disclose the sampling rates and physical locations of various visual cues used by drivers for vehicle control. As previously pointed out by Gordon (2), identification of the characteristics of drivers' visual sampling behavior will provide a rational basis for the design of driver aids and suggest improvements in highway design.

APPARATUS

The eye-marker camera used has been described in detail elsewhere (3) and only a brief description follows here. A cornea-reflection eye-marker camera (Polymetric

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Paper sponsored by Committee on Road User Characteristics and presented at the 48th Annual Meeting.

Figure 1. Eye-marker recording system.

Products Model V-0165-1L4) was modified by using a specially designed stabilization head unit in order to achieve accurate calibration and alleviate subject discomfort (Fig. 1). A beam splitter optically combined an eyespot reflected from the cornea and the scene that was transmitted through a wide-angle lens. The combined image was photographed by a 16-mm camera operated at 16 frames per second. At the same time eye movements were filmed, vehicle velocity, gas-pedal movements, and steering reversals were recorded on an oscillograph recorder. An instrumented 1963 Chevrolet was used as the test vehicle.

EXPERIMENT DESIGN

Two independent variables, route familiarity and driving condition, were studied. Driving condition had two levels, open-road driving and steady-state car following. For the open-road situation the drivers drove in the normal freeway traffic. When car following, they tried to keep a fixed distance (75 ft) between their vehicle and a lead car traveling at 50 mph. In order to experimentally manipulate route familiarity over a short period of time, verbal instructions were given to the driver. This allowed all three trials to be run in one data collection session. Thus, the results were not affected by different weather conditions, highway improvements, and changes in the drivers' physical and mental conditions.

On Trial 1 the drivers were told to follow a particular route and to read all road signs on the route; on Trial 2 they were to follow the same route and read only those signs necessary to successfully complete the route; and on Trial 3 they were to try to complete the route without reading any signs. Thus, Trial 1 attempted to simulate the driver who was totally unfamiliar with the route and was searching for directions, whereas Trial 3 attempted to simulate the driver who was very familiar with the route and needed little guidance information. Two similar routes (described below) were used for counterbalancing purposes. The experiment design is shown in Figure 2.

Routes

The two routes were designated A and B. Both routes were on the Columbus, Ohio, innerbelt expressway system and could be followed by reading route guide signs. Each route had two long, straight sections separated by two curves, several oncoming merges, several overpass bridges, and dense traffic. Route A was 2.7 miles in length and Route B was slightly shorter, 2.5 miles.

ROUTE FAMILIARITY

	Route A			Route B		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Open-Road Driving						
Car Following (Steady State)						

Figure 2. Experiment design—eye-movement workload study.

Subjects

The subjects were eight male college students whose ages ranged from 21 to 31. All had valid operators' licenses and a safe driving record. Seven of the subjects had at least 20-30 uncorrected vision. The eighth subject wore contact lenses that in no way distorted the eyespot or affected calibration accuracy.

Procedure

Each subject drove the vehicle for six trials. Three trials were open driving, and three trials were car following on a different route from the open driving. The order of presentation of driving conditions and routes was counterbalanced between subjects. The subjects drove the test vehicle and wore the eye-marker apparatus to the site of the trials. The eye-marker was calibrated by having the subject trace a target board that had two rows of three circular targets of 2-in. diameter. Adjacent targets were 1 ft apart and the board was placed 10 ft in front of the subject's eyes with the middle target of the bottom row centered at eye level. After the calibration was recorded on film the driver was told to memorize the following directions for Route A or Route B:

Route A

> You are to turn right onto Route 33-southeast. Once on Route 33, you are to enter the innerbelt by taking Route 71-south. After you are traveling south on the freeway, you are to take Route 70-east. Finally, you are to exit from the highway at the Fourth Street exit. Once you are on the exit ramp, we will instruct you where to pull over for a calibration.

Route B

> You are to turn onto Third Street heading south and enter the freeway by taking Route 70-east. Once on the freeway, you are to take Route 71-north. Once on 71-north, you are to follow the freeway to Route 40-west or Olentangy Road. You are to exit from the freeway by taking the Fourth Street exit. Once on the exit ramp, we will instruct you where to pull over for a calibration.

Then the instructions for the particular trial about to be run were read:

Trial 1

> During this trial you are to read all the road signs that you can, whether they pertain to the route you are to follow or not.

Trial 2

> During this trial you are to read only the road signs that pertain to the route that you are to follow.

Trial 3

> During this trial you are not to read any signs unless necessary to complete the route sucessfully.

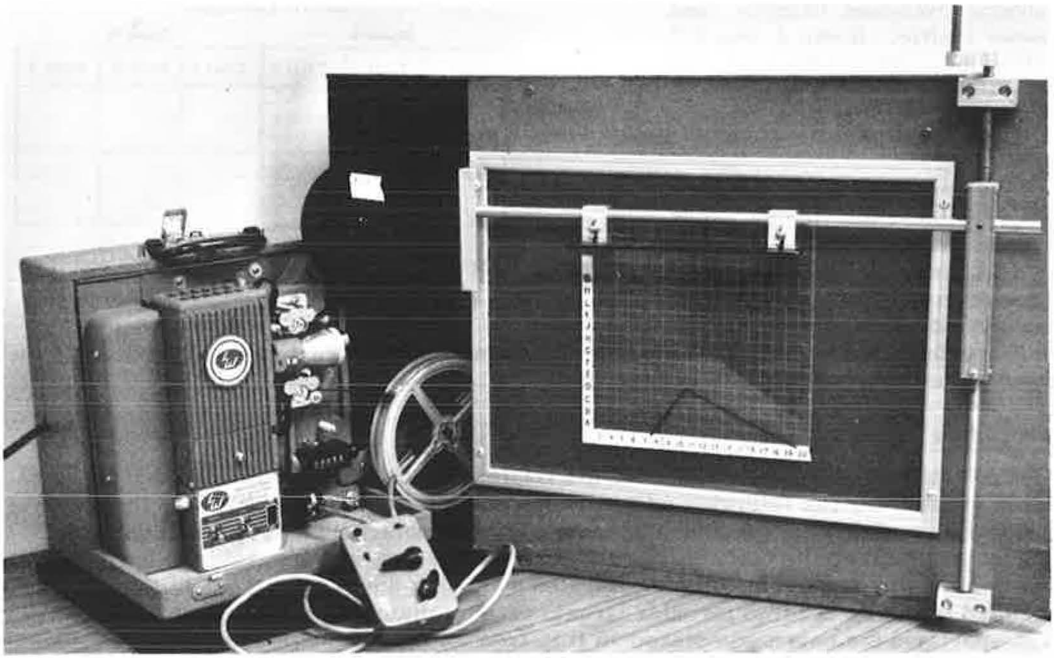

Figure 3. Sixteen-mm projector with data reduction grid.

For the open-driving condition, the subjects tried to travel approximately 50 mph. While car following, the subject tried to maintain a headway of about 75 ft with the lead car traveling at 50 mph. Calibrations were filmed at the end of each trial.

Data Reduction

The film was examined one frame at a time by using a Kodak Data Analyzer (LW Photo Model 224-A) and a rear-projection screen, which permitted viewing under normal indoor lighting conditions. For a constant reference, the right-edge and center-lane markers on the film were lined up with the corresponding edge markers on a data-reduction grid, which was superimposed on the rear-projection screen. The eyespot was then classified as being in one square of the data-reduction grid (Fig. 3). The eyespot was also classified into various categories depending on what the driver was looking at. The various categories were road signs, bridges, vehicles, road and lane markers, looking ahead, and out of view. Computer programs then summarized the data by providing a sequential listing of all fixation location matrices with respect to road geometry, histograms of fixation and travel distances, and various summary statistics.

TABLE 1

OUT-OF-VIEW CATEGORY STATISTICS
(One Subject)

Eye Movement	Time (sec)	Percent of Total Time (sec)	Average Time per Look (sec)
Looking in rear view mirror	10.8	6.9	0.61
Looking in side mirror	3.9	2.5	0.66
Monitoring speedometer	9.8	6.2	0.72
Blinking	8.5	5.4	0.16
Other	14.0	9.2	–

RESULTS

Because the out-of-view category represents the time when the eyespot is not on the film, it needs a special explanation. When large eye movements (greater than 10 deg from center) are unaccompanied by corresponding head movements, the eyespot does not appear on the film. This could happen when the subject looks at his speedometer or in his rear view or side mirror. The eyelid closing, as when blinking, also results in no eyespot on the film because there is no corneal reflection. In order to record these events, a TV camera can be placed on the dashboard of the car and focused on the driver's eye. At the same time eye movements may be recorded on 16-mm film with the eye-marker camera. Reduction and integration of the two records for one driver on one trial (open driving, Trial 1) produced the results shown in Table 1. (The out-of-view category for that trial accounted for 30.2 percent of the driver's total available viewing time.) Note that it took the driver about two-thirds of a second to look at either of the mirrors or the speedometer. When traveling at 60 mph you go 66 ft in two-thirds of a second. The large percent of time spent blinking (5.4) is partly

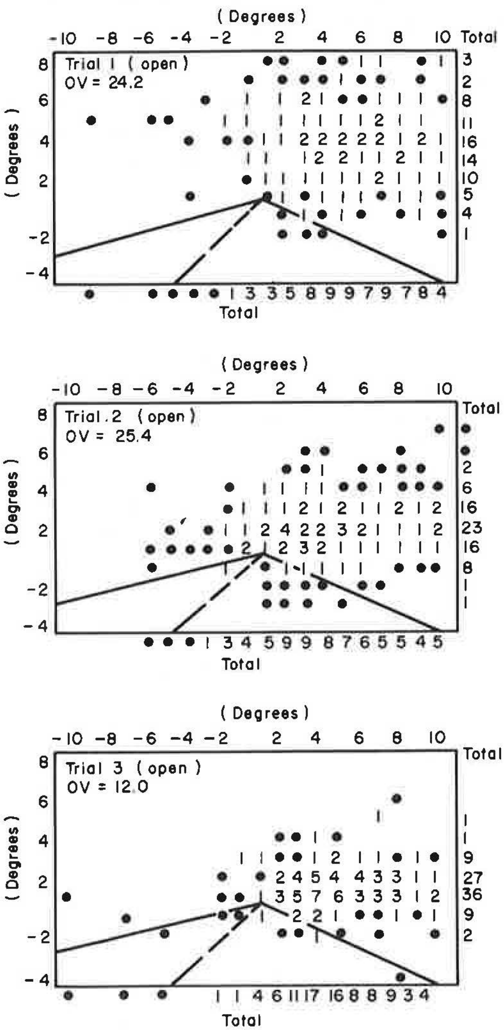

Figure 4. Percent of fixation time by location as a function of trials for open driving (one subject).

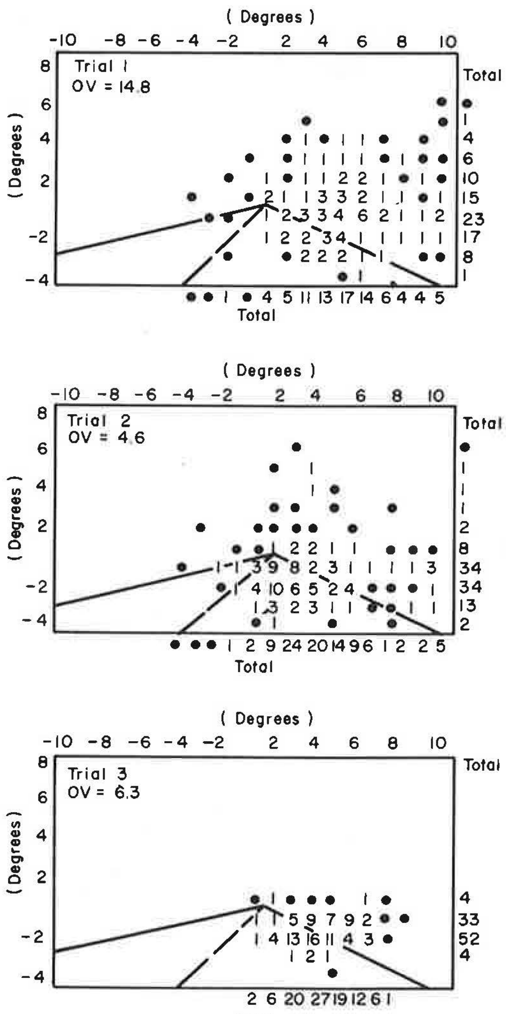

Figure 5. Percent of fixation time by location as a function of trials for car following (one subject).

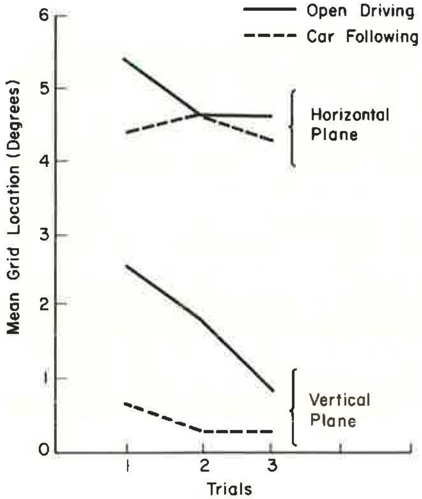

Figure 6. Central location of visual patterns by trials.

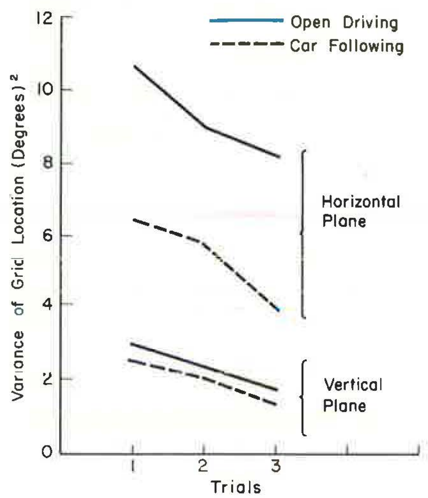

Figure 7. Variances of grid locations by trials.

compensated by the short blink duration (0.16 second). These statistics clearly indicate that the above events must be considered when describing the driver's visual task.

Search and Scan Patterns

A visual search and scan pattern may be represented by the percent of time spent fixating in 1 deg squares that are shown with respect to highway geometry. In Figure 4 is such a pattern for one subject for the three trials while open driving. If we disregard the trial effect for the moment, then

1. It is apparent that the driver fixated on the road and edge markers only a small percent of time.
2. The center portions of the patterns have the greatest percentages of time.
3. The central point for the pattern of Trial 3 is located about 1 deg above the driver's line of sight in the vertical and about 4 deg to the right side in the horizontal. This point is a good location in order to monitor lane position, other traffic, and vehicle velocity by using peripheral vision.

The effect over trials is that the pattern moved down and slightly to the left. In addition, the dispersion of eye movements decreased over trials.

In Figure 5 is the visual pattern for one subject during three trials while car following. The effect over trials is a marked decrease in dispersion, but there appears to be little change in pattern location. Note two of the differences between the car-following and open-driving patterns: (a) on all trials the car-following pattern is lower and more concentrated than that of open driving; and (b) the percent of time spent out of view (OV) is less for all trials while car following.

Although the above figures permit a qualitative analysis of visual patterns, it is also necessary to describe the patterns in terms of quantitative measures if comparisons are going to be made of the combined data of several drivers. This was done by computing mean locations of the visual pattern (weighted by fixation duration) separately for the horizontal and vertical planes. Then, means of horizontal and vertical locations could be averaged for all subjects. In Figure 6 is the mean location of the visual patterns for all subjects shown as a function of trials for the open-driving and car-following conditions. For open driving, the shift downward in the vertical plane was most pronounced. For car following, there was almost no downward shift. In the horizontal plane the shift from the right to the left occurred between Trials 1 and 2 for open driving. Again there was little shifting in the car-following situation.

In Figure 7 are the means of the location variances for the open-driving and car-following conditions as a function of trials. Note that a high variance is characteristic of a dispersed pattern, whereas a low variance is associated with a compact pattern. The following results are apparent:

1. In the horizontal plane, the car-following variances are lower than those for open driving on all trials.
2. In the vertical plane, the same effect holds but the magnitude of the differences is much less.
3. The variances decrease as a function of trials for all cases, with the decreases in the horizontal plane being twice those in the vertical plane.

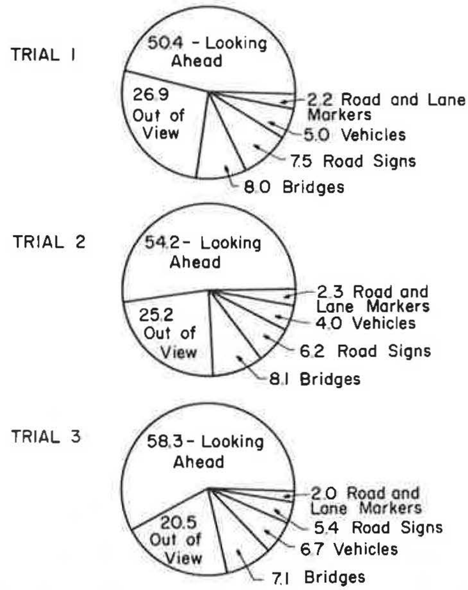

Figure 8. Viewing time percentages by categories—open driving.

Types of Information Sampled

Another effect of becoming familiar with the route can be seen from an examination of the percent of time the drivers visually fixated on each of the available information sources. In Figure 8 the viewing time percentages by categories for the open-driving condition are shown as a function of trials. Between Trials 1 and 3, (a) the percent of time in the looking-ahead category increased 7.9 percent; (b) the percent of time in the out-of-view category decreased 6.4 percent; (c) the percent of time looking at road signs decreased 2.1 percent; and (d) the percent of time spent sampling road and lane markers, bridges, and other vehicles remained fairly constant.

In Figure 9 the viewing time percentages by categories for the car-following condition are shown as a function of trials. Between Trials 1 and 3, (a) the percent of time in the lead-car category increased 5.5 percent; (b) the percent of time in the out-of-view category decreased 1.8 percent; and (c) the percent of time looking at road signs decreased 2.4 percent. Thus, in both the open-driving and car-following conditions the same type of changes occurred as a function of trials, i.e., an increase in time spent in the central viewing area and a decrease in time spent looking at road signs and in the out-of-view category.

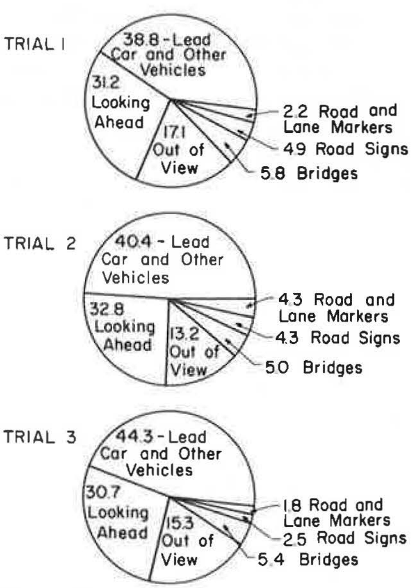

Figure 9. Viewing time percentages by categories—car following.

However, there are differences between the open-driving and car-following conditions. A comparison of Trial 3 data shows that (a) for car following, 75 percent of the time was in lead-car and looking-ahead categories, whereas for open driving, only 58.3 percent was in the looking-ahead category; (b) for car-following, 5.2 percent less time was in the out-of-view category, 2.9 percent less time was in the looking-at-road-signs category, and 1.7 percent less time was in the looking-at-bridges category. Thus, the greater time spent in maintaining a constant headway in the car-following task resulted in less time being spent in the road-sign, bridge, and out-of-view categories.

TABLE 2

MEAN FIXATION DURATION
(seconds)

Category	Open Driving			Car Following		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Lead car				0.32	0.30	0.31
Looking ahead	0.26	0.26	0.26	0.30	0.29	0.31
Bridges	0.30	0.27	0.29	0.32	0.31	0.28
Road signs	0.33	0.30	0.30	0.33	0.31	0.31
Vehicles	0.28	0.26	0.25	0.36	0.30	0.33
Road and lane markers	0.31	0.28	0.26	0.28	0.32	0.23
Out of view	0.51	0.48	0.37	0.39	0.27	0.30
Overall Means	0.27	0.26	0.27	0.32	0.30	0.30

Fixation Durations and Travel Distances

In Table 2 are the means of fixation duration by trial, driving condition, and category of object viewed. Although the overall mean fixation durations did not change over trials for either of the driving conditions, all the open-driving trials had shorter fixation durations than the car-following ones. Over trials the fixation durations decreased for the categories of road and lane markers and out of view.

In Table 3 are the means of travel distances by trials, driving condition, and category of object viewed. Travel distance is the length in degree that the eye traveled to get to the point of fixation. For open driving, the mean travel distance decreased as a function of trials for every category. For car following, although there was a decrease in every category of Trial 2, two categories of Trial 3 (vehicles and road and lane markers) showed an increase. When considering only Trial 3, mean travel distance is smaller for open driving than car following in all categories.

Histograms of fixation durations are presented for the three trials as a function of open driving and car following in Figure 10. Most apparent are the differences between the car-following and open-driving conditions. On every trial the percent of fixations that had durations between $1/10$ and $1/6$ sec was greater for open driving than car following. In addition, again on every trial, the percent of fixations with durations between $1/6$ and $2/6$ sec was greater for car following than open driving.

In an attempt to understand these differences, fixations between $1/10$ and $1/6$ sec were classified into categories for Trial 1 of the open-road and car-following driving conditions. In Table 4 are the number of fixations between $1/10$ and $1/6$ sec by category.

TABLE 3

MEAN TRAVEL DISTANCE
(degrees)

Category	Open Driving			Car Following		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Lead car				2.10	2.09	1.67
Looking ahead	2.08	1.98	1.80	2.42	2.16	1.91
Bridges	1.80	1.85	1.68	2.40	1.97	1.97
Road signs	2.32	1.97	1.92	2.60	2.25	2.10
Vehicles	2.35	2.03	1.94	3.09	2.57	2.80
Road and lane markers	2.57	2.30	2.08	2.32	1.83	2.45
Overall means	2.10	1.99	1.82	2.29	2.12	1.89

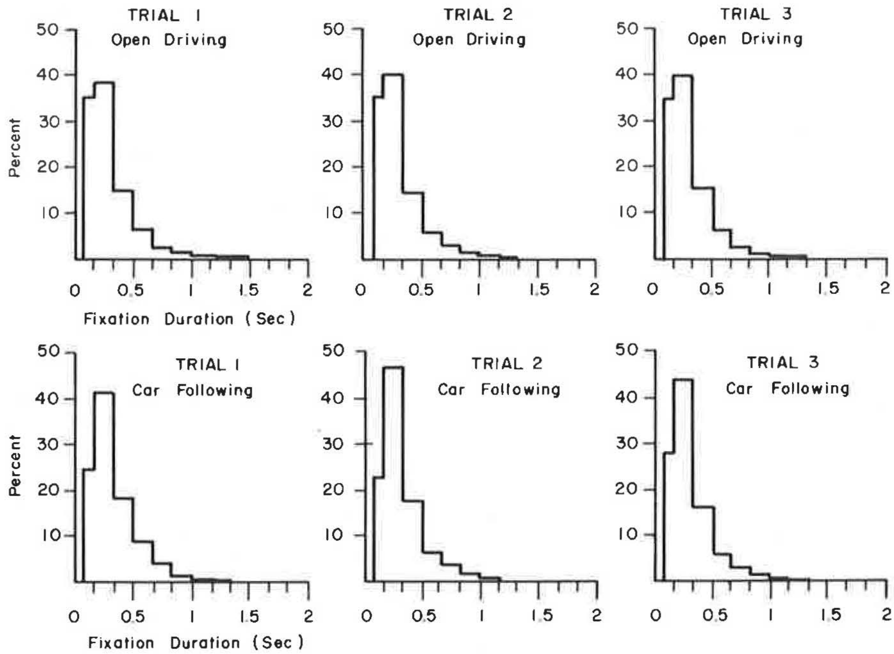

Figure 10. Fixation duration by trials and driving conditions.

TABLE 4

NUMBER OF FIXATIONS BY CATEGORY BETWEEN $\frac{1}{10}$ AND $\frac{1}{8}$ SECONDS
(Trial 1 only)

Category	Open Driving	Car Following
Lead car	—	278
Looking ahead	652	253
Bridges	103	43
Road signs	22	37
Vehicles	56	5
Road and edge markers	19	19
Total	852	635

The car-following situation had less fixations in the combined categories of lead car and looking ahead (531) than the open-driving condition had in looking ahead (652). More than twice as many fixations were made on bridges when open driving, and more fixations were made on road signs when car following. The greater number of fixations on vehicles while open driving is due to the lead car fixations being classified separately.

DISCUSSION OF RESULTS

For open driving, the most apparent differences between Trial 1 and Trial 3 were the shifting of the visual pattern down and to the left and the increasing of the pattern's compactness. This then resulted in more time being spent looking ahead, less time in the out-of-view category, and a decrease in visual travel distance.

In the car-following situation, the increases in compactness over trials suggests that the degree of drivers' route familiarity plays an important role in determining visual sampling strategies. During Trial 1, the drivers sampled a wide area in front of them, but on Trial 3, after gaining knowledge of their route, they confined their sampling to a smaller area.

Thus, it appears that the experience of becoming familiar with a route had a large effect on the visual sampling behavior of drivers. Because the driver who is familiar with the route spends more time looking ahead, he is better able to detect events that may possibly lead to situations that affect traffic flow or cause collisions.

The results lend support to the hypothesis that the peripheral area of the eye is used to monitor other vehicles and the road lane markers in order to direct the fovea for closer examinations when the situation demands it. Previous experimentation (4) has shown that peripheral-vision stimulation plays a large role in vehicle-velocity estimation because angular velocity is much greater in the peripheral than foveal areas. The same reason may be applied to the monitoring of other vehicles and road lane markers with peripheral vision. Because peripheral vision is used to monitor the road edge markers and because the peripheral portions of the eye have poor visual acuity, it is important to have good quality and easily detected lines. The slower visual sampling rate in car following may be due to visual sampling being confounded by judgment decisions. That is, because the drivers were asked to maintain a fixed distance between their vehicle and the lead car, they constantly had to judge whether they were too close or too far. Thus, the visual judging of too close or too far and/or the associated control response of gas pedal and brake movements may be responsible for the increase in fixation duration while car following.

These findings offer ideas that may lead to the development of visual aids for the unfamiliar driver. It is apparent that the searching for and reading of road signs by the unfamiliar driver results in more dispersed visual patterns than normal. One way to prevent this is to place route guidance information directly in the driver's line of sight. This may be done by using a head-up display. Because the messages projected on the display are focused at infinity and appear superimposed on the driver's field of view, it is possible to simultaneously read the messages and monitor the normal visual stimuli needed for vehicle control. This should make the visual task of the unfamiliar driver more like that of the familiar driver. A description of a head-up display designed for longitudinal control aiding and its subsequent testing has recently been reported by the Systems Research Group (5).

ACKNOWLEDGMENTS

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Passing Behavior on Public Highways Under Daytime and Nighttime Conditions

EUGENE FARBER, Franklin Institute Research Laboratories, Philadelphia

This study was designed to determine the effect of nighttime visibility conditions on the passing behavior of drivers on two-lane public highways. The experiment was observational in the sense that the drivers whose passing behavior was observed happened along fortuitously and had no idea that they were taking part in an experiment, or that their passing behavior was being observed. The data were obtained only at night, but at the same site and under identical conditions in which data were collected during the day in a previous Franklin Institute contract with the U. S. Bureau of Public Roads. The daytime data from the previous contract are reported along with the nighttime data in the presentation of the results.

•EARLIER WORK, performed by a number of state and federal highway agencies to provide highway engineers with design information for laying out passing zones, is reviewed in detail by Farber and Silver (1967). Many of the data are concerned with the time and distance required to pass, and relatively little information is presented on passing decision-making—the conditions under which a driver will or will not pass. In the present study, although passing times and distance were recorded, the basic experimental approach was to determine the relationship between the likelihood that a driver would accept a passing opportunity and the time, speed, and distance variables that determine the acceptability of the passing opportunity.

For the purposes of this study, a passing opportunity is defined to exist whenever (a) a driver is in a close following position behind a lead car, LC, whose speed is less than the desired speed of the following car driver, and (b) both vehicles are in a legal passing zone. A passing opportunity starts the moment that the following car crosses into the passing zone. One passing opportunity ends and another begins each time an oncoming car, OC, traveling in the opposite lane comes abreast of the LC. If, after the start of a passing opportunity, no OC is within the view of the would-be passer, the passing opportunity ends when the LC leaves the passing zone. A passing opportunity that ends with the passage of an OC is called oncoming-car-limited; a passing opportunity that ends with the end of the passing zone is called sight-distance-limited.

Objectively, the acceptability of an oncoming-car-limited passing opportunity is given by comparing the minimum passing time of which the passing car, PC, is capable with the LC-OC time separation at the start of the passing opportunity. This time separation has been designated passing-opportunity time, POT. Passing-opportunity distance, POD, is defined as the distance between the lead and oncoming cars at the start of the passing opportunity. Passing-opportunity time is given by

$$\mathrm{POT} = \mathrm{POD}/\mathrm{CR}$$

where CR is the closing rate, which is the sum of OC and LC speeds. In a sight-distance-limited passing opportunity, the passing-opportunity time is given by

$$\mathrm{POT}_{SD} = \mathrm{SDR}/\mathrm{LCS}$$

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where SDR is the amount of sight-distance remaining from the point of the start of the passing opportunity, and LCS is the speed of the LC. Because the minimum passing time of a given vehicle is relatively constant at highway speeds, the acceptability of a passing opportunity depends almost solely on the passing-opportunity time. Thus, the ability of drivers to make accurate passing decisions (to pass if, and only if, it is safe) depends on their ability to judge passing-opportunity time. Because passing-opportunity time is the duration of an event that has not yet occurred—the amount of time that will have elapsed between the start of the passing opportunity and the moment the OC and LC come abreast—it cannot be judged directly; it can only be predicted, solely on the basis of passing-opportunity distance and closing rate. Thus, whether or not the driver thinks in these terms, he must judge passing-opportunity distance and closing rate, taking the latter appropriately into account in order to estimate passing-opportunity time and make a valid passing decision.

The ability of drivers to make these judgments has been treated by Bjorkman (1963), Crawford (1963), and Rockwell and Snyder (1965). Taken together, the results of these studies suggest that drivers are relatively good judges of distance in passing situations but poor judges of either closing rate with an oncoming car or oncoming-car speed. Michaels (1963) provides a basis for understanding this insensitivity to OC speed. His data suggest that at the distance at which most passes take place, the speed cue associated with the rate of change of the visual angle subtended by the OC is below threshold. These papers are reviewed by Farber and Silver (1967).

These findings were confirmed in the studies performed under the previous contract. In the daytime observational studies, it was found that in passing on the public highways drivers were insensitive to OC speeds but responded appropriately to passing-opportunity distance and LC speed. That is, the greater the LC speed, the less likely a driver was to pass at a given distance.

METHOD

The observational technique, developed under the previous contract, was used without change in this study and is described in the following paragraphs.

Test Site

The tests were conducted on a 2-mile section of Route 47 near Vineland, New Jersey, which incorporated a no-passing zone and two passing zones (Fig. 1). The north and south passing zones were 3,200 and 5,400 ft long respectively. The no-passing zone was 1,900 ft long. Sight distance in the no-passing zone was restricted to a maximum of 900 ft by an S curve and the crest of a slope. Both of the passing zones were straight and level and afforded unrestricted sight distance for their entire lengths. The north passing

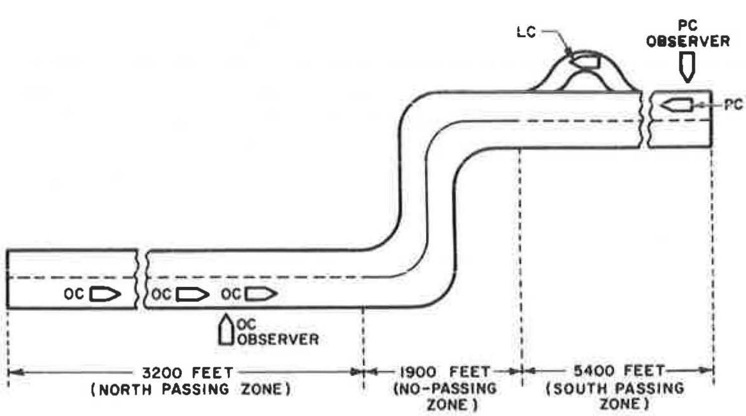

Figure 1. Observational-study test site and position of observers.

zone terminated at a curve at its northern extreme at which point there was still 800 ft of sight distance. The roadway was 24 ft wide with a blacktop surface and 4-ft gravel shoulders, and was in good condition at the time of the study. All of the data reported below were collected in the north passing zone.

Vehicles and Instrumentation

One observer was positioned in each of three vehicles. Before the start of an observational trial, one vehicle, designated the LC, was parked on the right-hand shoulder in the south passing zone near the beginning of the no-passing zone (Fig. 1). The other two vehicles were used as observation stations and their positions were fixed throughout the observation period. The PC observer was stationed well off the highway of the south passing zone, on the same side of the road as the LC, several hundred yards before the beginning of the no-passing zone. The OC observer's vehicle was stationed off the highway in the north passing zone several hundred yards beyond the end of the no-passing zone. The LC and OC observers' vehicles were equipped with manually operated Rustrack Model 92 4-channel event recorders, powered by the car battery. The PC observer had a slide rule and a stopwatch.

Procedure

When a single, nonfollowing passenger vehicle, designated the PC, was observed in the south passing zone driving north toward the no-passing zone, the LC pulled onto the road in front of it and led it into the no-passing zone. The "free speed" of the PC (speed while in the south passing zone) was determined by the PCobserver who timed it between two calibrated landmarks and used a slide rule to convert the time to speed. The speed of the PC was radioed ahead to the LC driver who then led the PC through the no-passing zone at some speed lower than its recorded free speed. When this procedure was followed, the PC invariably matched its speed with that of the LC and assumed a close following position by the time the end of the no-passing zone was reached. The behavior of the PC through the passing zone was recorded by the LC driver on the event recorder. The speeds of all oncoming vehicles encountered by the LC driver in the passing zone area where recorded by the OC observer. The procedures for recording passing data and OC speeds are described below.

Recording Passing Data

When the LC reached the end of the no-passing zone, the driver pulsed (momentarily depressed) the button controlling channel 1 of his event recorder. Channel 1 was pulsed again each time an OC traveling in the opposite lane came abreast of the LC. When the PC began a pass, channel 2 was pulsed the moment the left front wheel of the PC crossed the center dividing line. Channel 2 was pulsed again at the completion of the pass when the left rear wheel of the PC recrossed the dividing line. If the pass was aborted, channel 3 was pulsed when the left front wheel recrossed the dividing line. After the pass, the LC driver maintained a constant speed until the end of the passing zone was reached, at which point channel 4 was pulsed, or until another OC came abreast of the LC, at which point channel 1 was pulsed. Subsequent reduction of the LC record yielded the following data for each passing opportunity: passing-opportunity time, whether or not a pass took place; and decision time, passing time, and safety-margin time in passing opportunities where there was a pass. Decision time is the time between the start of a passing opportunity and the start of a pass. Passing time is the time between the start and the completion of a passing maneuver. Safety-margin time is the time between the completion of a pass and the moment that an oncoming car comes abreast of the LC.

Figure 2 is a typical LC event-recorder record. Each interval between successive channel 1 pulses represents a distinct passing opportunity. Passing-opportunity time is determined by measuring the time represented by the distance between the leading edges of successive channel 1 pulses. Decision time is the time between the channel 2 pulse and the preceding channel 1 pulse, the time between channel 2 pulses is passing time, and the time between a channel 2 pulse and the following channel 1 pulse is safety-

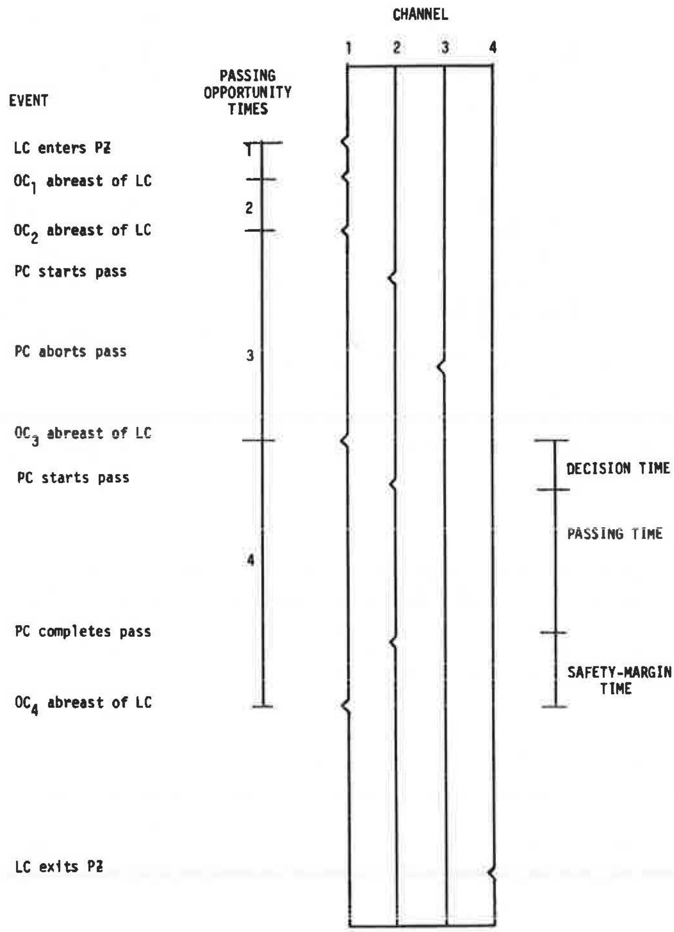

Figure 2. Example of lead car event-recorder record.

margin time. If after a pass no OC came abreast of the LC before the end of the passing zone was reached, a channel 4 pulse was recorded instead of a final channel 1 pulse. Thus, the distance between the channel 2 and channel 4 pulses represents the time from the completion of the pass until the LC reached the end of the passing zone.

Recording Oncoming Car Speeds

During a trial, as the LC driver approached the beginning of the passing zone, he alerted the OC observer by radio. The OC observer then began to record the passage of the OC's on his event recorder. Like the PC observer, the OC observer used a "time trap" (pair of calibrated landmarks) for timing OC's. The channel 1 button was momentarily depressed each time an OC came abreast of the first landmark, and the channel 2 button was depressed when the OC came abreast of the second landmark. An event recorder, rather than a stopwatch, was used because as many as four or five cars might be in the time trap at the same time. Figure 3 shows a typical OC observer's event-recorder record.

Subsequently, the LC and OC observer's event recorders were matched, and the speed of each OC was noted on the LC record. Because the speeds of the LC and of each OC were known, all the times taken from the LC event recorder could be converted into distances.

Calibration of Event-Recorder Chart Speeds and Speedometer

The chart speed of each event recorder was checked each day by measuring the length of a 30-sec pulse.

The LC speedometer was checked once a week by timing it across a known distance at a constant speed. This speedometer check was repeated several times at each of several different speeds.

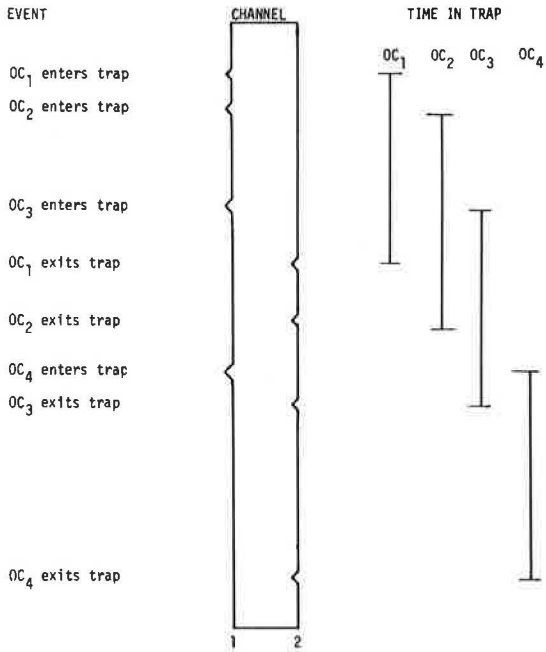

Figure 3. Example of oncoming-car observer's event-recorder record.

EXPERIMENTAL DESIGN

A desirable feature of the technique described previously is that the LC driver can exercise a measure of experimental control over what is essentially an observational situation by controlling the PC speed to impede the PC by 10, 15, or 20 mph less than its recorded free speed. When the PC observer radioed the free speed of the PC to the LC driver, the LC driver consulted a table to determine the speed impedance for that trial. If, for example, the impedance for that trial was 15 mph and the free recorded speed of the PC was 45 mph, the LC driver proceeded through the no-passing zone at 30 mph. The purpose of this procedure was to determine the effect of the degree of speed impedance on passing decisions.

A 5-mph impedance was contemplated but not used because small variations in LC and PC speeds (±2 to 3 mph) were frequently sufficient to reduce the PC-LC closing rate to null. On the assumption that there is no three-car cycle of characteristics in traffic that would be confounded with impedance, no attempt was made to randomize the order of impedance and they were simply alternated.

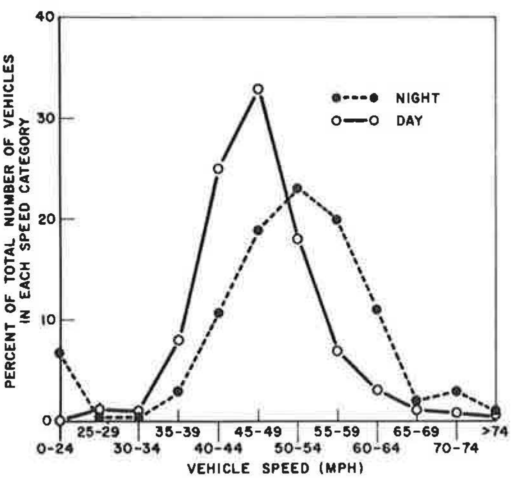

Figure 4. Distribution of vehicle speeds expressed as percent of total vehicles in each speed category for day and night conditions.

TRAFFIC CHARACTERISTICS

During the nighttime observation periods, the average one-way traffic volume ranged from 190 vehicles per hour an hour after sunset to 70 vehicles per hour later in the evening. During the day, traffic volume ranged from 100 to 200 vehicles per hour. Traffic volume was the same in both directions. Eighty-five percent of the traffic consisted of passenger vehicles. The distribution of vehicle speeds was the same in both directions and is shown in Figure 4, which also shows daytime speed distribution. Speeds were generally higher and more variable at night than they were during the day. The average daytime speed was 47 mph with a standard deviation of 7.49. The average nighttime speed was 53 mph with a standard deviation of 9.27. Eighty-two percent of the vehicles observed at night were between 40 and 65 mph when their speed was recorded.

The frequency distribution of passing-opportunity distance observed at the Vineland site, both at night and during the day, is plotted in Figure 5. At night and during the day the frequency monotonically decreases with increasing passing-opportunity distance. The night distribution is less steep than the day; i.e., there were relatively more long passing opportunities (greater than 2,400 feet) and fewer short passing opportunities (less than 2,400 feet) at night than during the day. This is to be expected as traffic volume was less at night than during the day.

Figure 6 shows the distribution of sight-distance-limited passing opportunity distances. In almost every trial that resulted in a sight-distance-limited passing opportunity, there was at least one OC in the passing zone as the LC entered the passing zone. Sight-distance-limited passing opportunities began as the last of the OC's and the LC passed each other. Because there was frequently more than one OC in the passing zone during the trial, many sight-distance-limited passing opportunities did not begin until the LC was toward the end of the passing zone. Thus, as Figure 6 shows, there was a preponderance of short opportunities.

RESULTS

All of the data reported below were obtained after dark at the Vineland observation site over a period of four weeks. It was hoped that during this period there would be sufficient precipitation to make a meaningful analysis of its effects; however, it rained only three times during the test period. On two occasions, the rain was light and the duration brief and only a few passing opportunities were observed. On the third occasion, the rain was so heavy that traffic came to a virtual standstill, and no data were collected at all.

A total of 2,221 passing opportunities was observed. Of these, 222 observations were discarded because of ambiguities in the data, errors in the test procedure, or faulty equipment. Of the 1,999 recorded passing opportunities, 1,744 were OC-limited and 255 were sight-distance-limited. There was a total of 420 passes; 323 in OC-limited passing opportunities and 97 in sight-distance-limited opportunities.

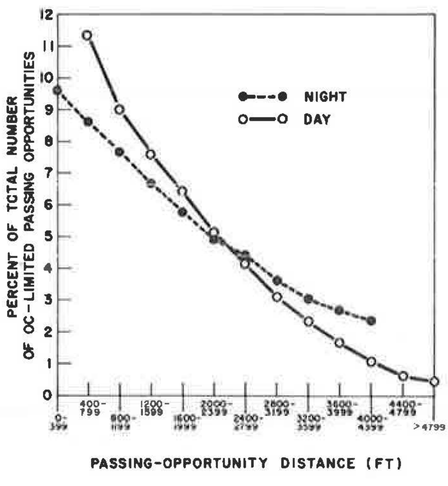

Figure 5. Distribution of passing-opportunity distances expressed as percent of total number of oncoming-car-limited passing opportunities.

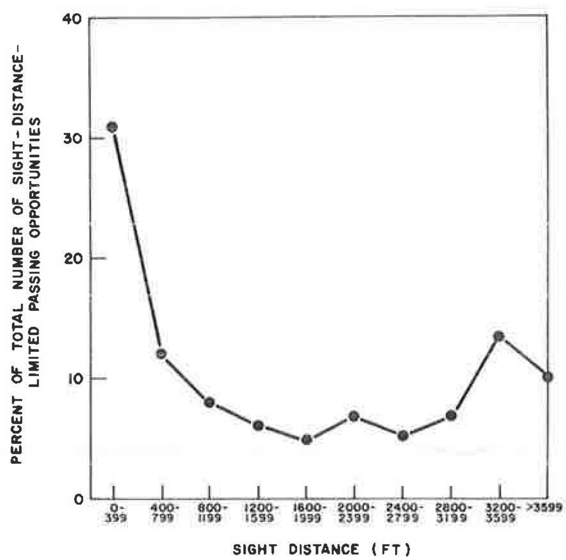

Figure 6. Distribution of passing-opportunity sight distances expressed as percent of total number of sight-distance-limited passing opportunities.

Oncoming-Car-Limited Passing Situations

This section is devoted to driver decision-making and performance in OC-limited passing situations. The data on sight-distance-limited passing situations are presented in the conclusion of this paper. In all of the figures in this section, the daytime data obtained in the previous contract are plotted along with the nighttime data to facilitate comparison.

Passing Decisions—Figure 7 shows percent passes as a function of passing-opportunity distance interval combined for all speed and impedance conditions under day and night conditions. Each point on the curve represents the percentage of passing opportunities observed in a given interval that were accepted. The threshold passing-opportunity distance—that passing opportunity during which 50 percent of the drivers passed—was 2, 050 ft during the day and 2,800 ft at night. Clearly, under both daytime and nighttime conditions, the likelihood that the driver would pass increased with increasing passing-opportunity distance. However, at a given passing-opportunity distance, drivers were more likely to pass during the day than at night. The overall difference between curves is significant ($P < 0.01$). Both curves approach an asymptotic passing frequency of 90 percent at passing-opportunity distances over 3,600 ft. There appears to be little difference between the two curves at short (less than 1,400 ft) passing-opportunity distances. However, no passing opportunities between 400 and 800 ft were accepted at night, whereas 4 percent of such passing opportunities were accepted during the day. This difference is significant ($P < 0.01$).

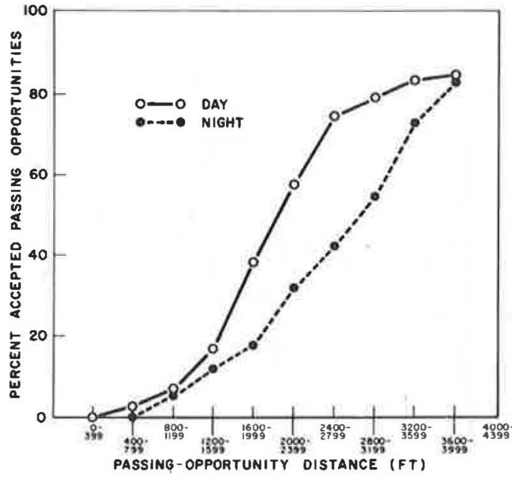

Figure 7. Percent accepted oncoming-car-limited passing opportunities as a function of passing opportunity under day and night conditions.

Passing-decision behavior was less variable during the day than at night as indicated by the greater steepness of the day-data slope. By treating these curves as integrals of the distribution of those passing-opportunity distances judged by drivers to be equal to their threshold passing-opportunity distances, it was possible to estimate the standard deviations of the underlying distributions. This procedure was used to estimate the standard deviations of the day and night distributions in Figure 7, 950 and 1,300 ft respectively. The difference between the associated variances is significant ($P < 0.01$). The greater nighttime variability probably reflects the somewhat poorer OC distance judgment under nighttime conditions observed in a previous experiment. (The results of this experiment are in "Judging the Distance to an Oncoming Car at Night and During the Day", an unpublished FIRL report of research conducted under the same BPR contract as the present study.) The nighttime variability may also reflect greater nighttime individual differences in what drivers consider to be an acceptable passing-opportunity distance.

If 13 sec is taken to be a minimum acceptable passing-opportunity time (8 sec for passing and a 5-sec safety margin), then the acceptable passing-opportunity distances, computed on the basis of median OC and LC speeds, are 1,600 and 1,800 respectively for day and night. If these figures are used as minimum acceptable passing-opportunity distances, then 42 percent of the acceptable nighttime passing opportunities were rejected and 25 percent of acceptable daytime passing opportunities were rejected.

Figure 8 shows percent accepted passing opportunities as a function of passing-opportunity distance under day and night conditions for three different categories of LC speed. The extreme variability of the less-than-25-mph nighttime data is due to the relatively small sample of passing opportunities in that category. Despite this variability, it is clear that under both daytime and nighttime conditions, the likelihood that a

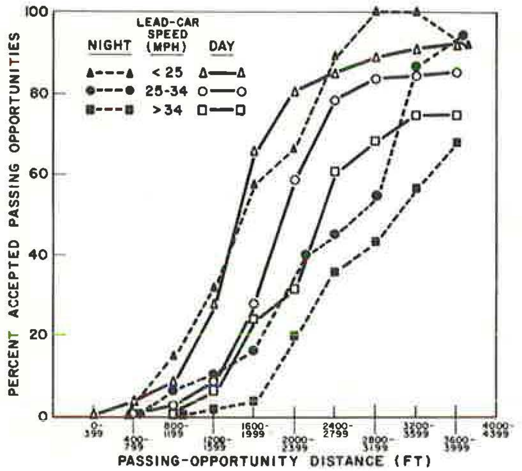

Figure 8. Percent accepted oncoming-car-limited passing opportunities as a function of passing-opportunity distance for three lead car speed categories under day and night conditions.

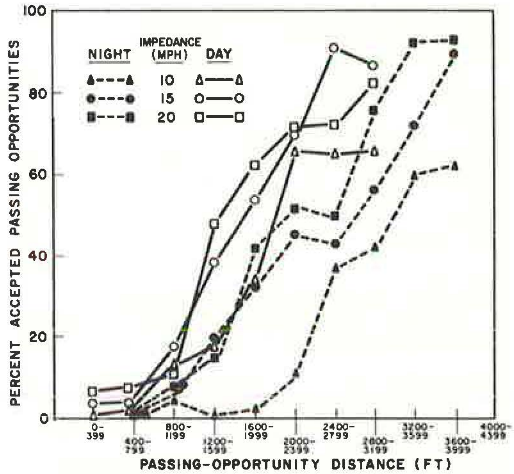

Figure 9. Percent accepted oncoming-car-limited passing opportunities as a function of passing-opportunity distance for three levels of impedance under day and night conditions.

driver would pass at a given opportunity distance increased with a decrease in LC speed. Drivers compensated appropriately for LC speed by adopting longer passing-opportunity distance thresholds at higher LC speeds. In fact, at night, at LC speeds over 34 mph, drivers were reluctant to pass. The threshold passing distance in this category was about 3,000 ft and the asymptotic passing frequency was about 70 percent.

Figure 9 shows percent accepted passing opportunities as a function of passing opportunity distance for the three difference levels of impedance under day and night conditions. These data should be interpreted with caution because impedance is partially confounded with LC speed. Under both daytime and nighttime conditions, the trend of the data suggests that the greater the impedance, the more likely a driver is to pass at a given distance. This effect is somewhat more clear-cut in the nighttime data than in the daytime data and is valid only for passing-opportunity distances in excess of 1,200 ft.

Neither at night nor during the day did drivers respond systematically to the speed of oncoming traffic. Under both day and night conditions, a driver was as likely to pass when the OC was traveling at 60 mph as when it was traveling at 30 mph.

Two major components of variability in the passing frequency curves are distance judgment and individual differences between drivers on what they consider to be an acceptable passing-opportunity distance. A third source of variability is LC speed. Because it includes the smallest range of LC speeds, the 25- to 34-mph passing frequency distribution is assumed to have the smallest variability because of the LC speed of the three LC-speed category curves. The standard deviations for the day and night 25- to 34-mph passing frequency curves were estimated to be 700 and 1,000 ft respectively. These standard deviations are substantially higher than those obtained in the OC-distance judgment experiment cited previously. In that experiment, the standard deviations of distance judgments of the worst subjects were 315 and 235 ft respectively for night and day conditions. The distance judgment of the unsuspecting subjects in the present study was probably somewhat worse than that of the subjects of the controlled distance judgment experiment. However, it is unlikely that poorer distance judgment alone accounts for the very large differences between the standard deviations observed in the distance judgment experiment and those associated with the passing frequency curves. Rather, the data suggest that a substantial proportion of the passing judgment variability observed on public highways is due to individual differences in what the drivers consider to be an acceptable passing-opportunity distance. This suggests that drivers who accept hazardously short passing-opportunity distances (e.g., less than 1,000 ft) do so not because they err by 1,500 ft in judging a passing-opportunity distance, but because their passing thresholds are small to begin with. Thus, it is likely that high-risk passing is more a consequence of choice than of error. Nevertheless, it is obvious that for drivers whose nominal passing-opportunity distance threshold is around 1,200 ft, even a small error in judgment can result in the acceptance of an extremely hazardous passing opportunity.

A passing-opportunity distance of 1,200 ft is equivalent to a passing-opportunity time of 10 sec at an OC-LC closing rate of 82 mph. Acceptance of such a passing opportunity is certainly imprudent but not necessarily hazardous, as most American passenger sedans are capable of completing an accelerative pass in under 8 sec. However, the results of the distance judgment experiment indicate that at an LC-OC distance of 1,200 ft, the standard deviation of distance-judgment errors is approximately 150 ft during the day. A driver with a 1,200-ft threshold would thus be expected to accept about 5 percent of all 950-ft passing-opportunity distances. At a closing rate of 82 mph, a 950-ft distance is equivalent to a passing opportunity time of 7.9 sec, a 20 percent shorter and substantially more hazardous passing-opportunity time than associated with the 1,200-ft passing-opportunity distance.

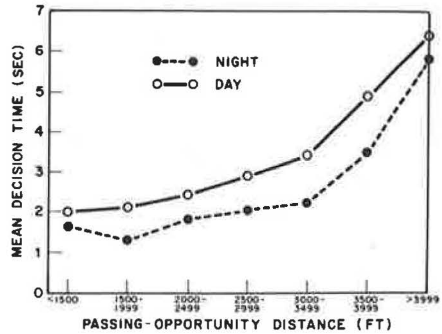

Figure 10. Mean decision time of drivers who accepted oncoming-car-limited passing opportunities as a function of passing-opportunity distance under day and night conditions.

A further source of error in the acceptance of short passing-opportunity distances, even when distance judgment is good, is the inability of drivers to judge OC speed. Depending on the OC speed observed, passing-opportunity times equivalent to a 1,200-ft passing-opportunity distance ranged from less than 8 to more than 15 seconds at LC speeds close to 30 mph. Because drivers are not able to accurately compensate for OC speed, accepting short passing opportunities may be distinctly hazardous at the 95 percentile OC speed. It is clear from the empirical passing frequency curves that most drivers adopt a passing-opportunity distance threshold that allows for considerable error in judgment.

That drivers are more conservative at night than during the day, as shown in Figure 7, probably reflects the adaptation of longer thresholds to compensate for the somewhat poorer nighttime OC-distance judgment. It could also be argued that drivers are less likely to pass at night under any conditions because with the poor nighttime visibility the task of tracking around a lead vehicle is itself more difficult. However, the asymptotic passing probability was as high at night as during the day. Poor nighttime distance judgment probably accounts for a part of the greater nighttime variability, but the difference in day and night OC-distance judgment is not enough to account for the difference in variability between the day and night passing frequency curves. This suggests that individual differences in desired passing thresholds may be greater at night than during the day.

Passing Performance—For drivers who did pass, there are three parameters that are of particular interest: decision time, passing time, and safety-margin time. Figure 10 shows mean decision time in seconds as a function of passing-opportunity distance. The highest mean decision time was around 6.4 sec and occurred at the longest passing-opportunity distance. The mean decision times increased monotonically with passing-opportunity distance and were at a minimum at passing-opportunity distances less than 1,500 ft.

Mean decision times were consistently less at night than during the day by 0.4 to 1.1 seconds. Although the data are highly variable (standard deviations ranged from 2 to 5 sec) the effect is significant ($P < 0.01$) and may reflect drivers' awareness of the higher nighttime traffic speeds.

Figure 11 shows mean passing time as a function of passing-opportunity distance under both day and night conditions. Under both day and night conditions, passing time

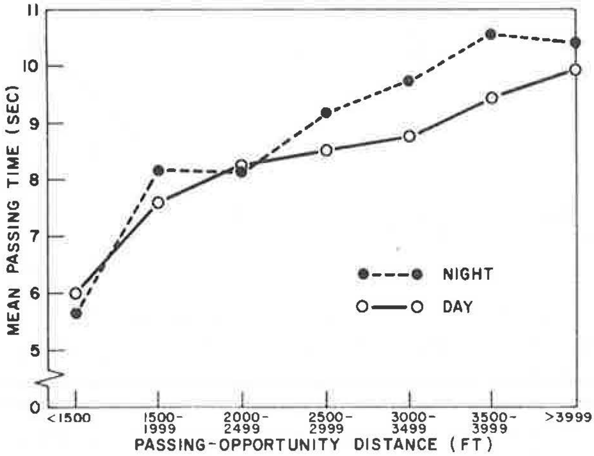

Figure 11. Mean passing time of oncoming-car-limited passes as a function of passing-opportunity distance under day and night conditions.

increased with passing-opportunity distance. Mean passing times were slightly (0.6 to 1.0 sec) less during the day than at night at the passing-opportunity distance over 2,500 ft; but at shorter passing-opportunity distances, night passers were apparently willing to use the full acceleration potential of their vehicles and there was little difference between day and night passing times.

Figure 12 shows mean safety-margin time for drivers who passed as a function of passing-opportunity distance and LC speed under day and night conditions. Above 2,000 ft, the day and night data are strikingly similar; safety margins increase with increasing passing-opportunity distance and with decreasing LC speed. Below 2,000 ft, the data become more variable because of the relatively small number of observations represented by each point. The slightly higher mean safety margins observed for drivers who passed at night at passing-opportunity distances less than 1,500 ft is a consequence of the fact that at night there were no passes at passing-opportunity distances less than 800 ft, whereas several such passes were recorded during the day. The mean of accepted passing-opportunity distances less than 1,500 ft was thus higher at night (1,320 ft) than during the day (1,120 ft). Although drivers did adjust their gap-acceptance thresholds in the appropriate direction in response to LC speed, the fact that safety margins diminished with increasing LC speeds indicated that drivers did not compensate perfectly.

Figures 10 through 12 indicate that passing performance in OC-limited passing situations was not strongly affected by nighttime visibility. At passing-opportunity distances greater than 2,500 ft, drivers passed somewhat more quickly during the day; but at shorter distances, where more rapid passing is required to ensure an adequate safety margin, there was no difference between day and night passing. Decision times were consistently about ½ to 1 sec less at night than they were during the day. These findings suggest that night visibility conditions do not have a strong cautionary effect on the dynamics of the passing maneuver.

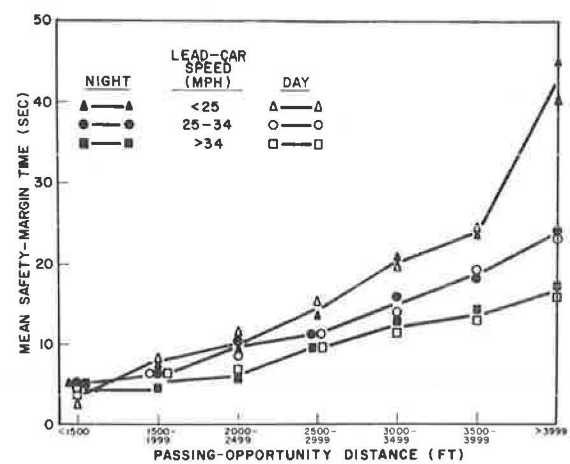

Figure 12. Mean safety-margin time in oncoming-car-limited passes as a function of passing-opportunity distance for three categories of lead car speed under day and night conditions.

Sight-Distance-Limited Passing Situations

The following paragraphs deal with driver decision-making and performance in sight-distance-limited passing opportunities, i.e., those passing opportunities in which no OC was in sight and sight-distance remaining was the limiting factor. Although the passing zone was 3,200 ft long, the total sight distance from the start of the passing zone was 4,000 ft. Because no daytime sight-distance-limited passing opportunities were observed, all of the data reported below were obtained under nighttime conditions.

Passing Decisions—Figure 13 shows percent passes as a function of sight-distance remaining (SDR). The threshold SDR (that SDR at which 50 percent of the passing opportunities were accepted) was 1,750 ft. The asymptotic passing frequency was 90 percent and the standard deviation was about 1,000 ft. No drivers passed when the sight distance was less than 500 ft, but 15 percent passed when the sight distance was between 500 and 1,000 ft. In general, drivers accepted substantially shorter sight-distance-limited passing opportunities than OC-limited passing opportunities. The rate at which the available passing-opportunity distance diminishes is roughly twice as great when an OC is the limiting factor as when sight distance is the limiting factor. However, even in a sight-distance-limited passing situation, it is not the sight distance or lack of it per se that gives rise to caution, but the possibility that an OC will appear after the driver has committed himself to a passing maneuver. Thus, on truly rational grounds, it makes no more sense to accept a sight-distance-limited passing opportunity of 1,000 ft than it does to accept an OC-limited passing opportunity of 1,000 ft. In view of this, the fact that drivers are willing to accept shorter sight-distance-limited than OC-limited passing opportunities suggests that their subjective estimates of the likelihood of oncoming traffic play a role in the passing decision. If this is the case, it would be expected that drivers would be more likely to accept a sight-distance-limited passing opportunity of a given length when oncoming traffic is light rather than when it is heavy. However, these data were obtained at night and it is quite likely that the headlights of otherwise out-of-sight OC's provided a reliable and acceptable cue to would-be passers as to the presence or absence of oncoming traffic.

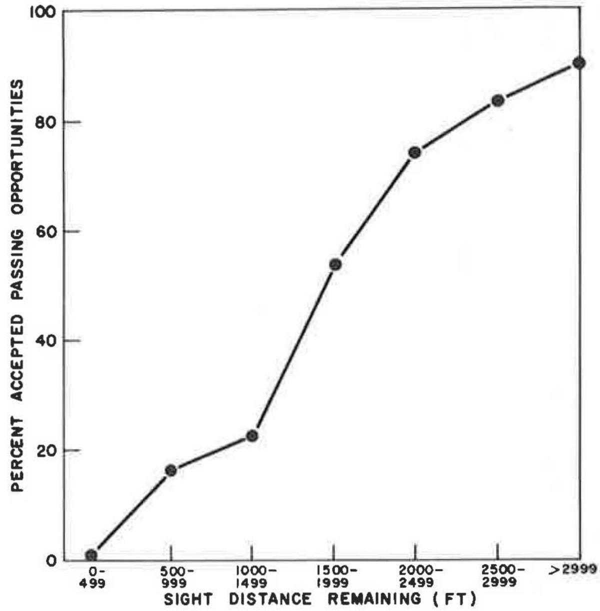

Figure 13. Percent accepted sight-distance-limited passing opportunities as a function of sight-distance remaining.

Figure 14 shows percent sight-distance-limited passes accepted as a function of sight-distance remaining for LC speeds above and below 30 mph. Because of the relatively small number of sight-distance-limited passing opportunities observed (420), it was not possible to break LC speed into more than two categories. LC speed has a strong effect on passing frequencies. At LC speeds greater than 30 mph, a driver is less likely to accept a passing opportunity at a given sight-distance remaining than at LC speeds less than 30 mph. Although the distance required to pass is

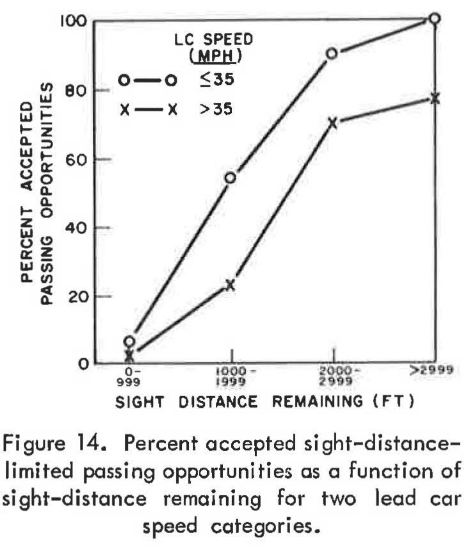

Figure 14. Percent accepted sight-distance-limited passing opportunities as a function of sight-distance remaining for two lead car speed categories.

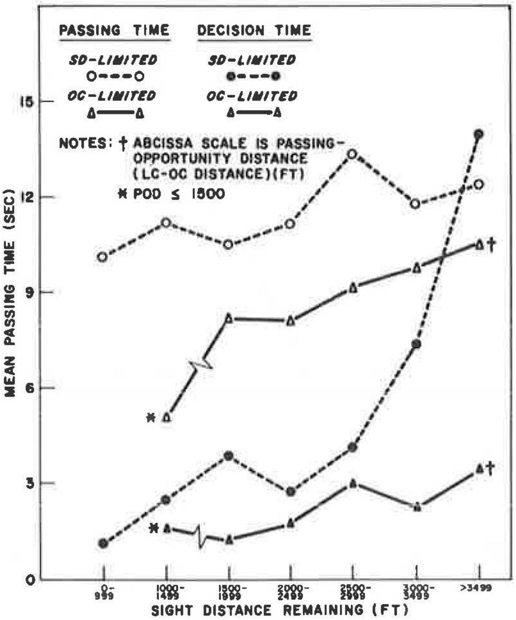

Figure 15. Mean passing time and mean decision time as a function of sight-distance remaining.

greater when the speed of the LC is high, this factor alone is not sufficient to account for the differences between the over and under 30-mph curves. Of those drivers who accepted passing opportunities in excess of 3,000 feet, the average passing distances for the over and under 30-mph speeds were 530 and 740 ft respectively. At sight distances in excess of 3,000 ft, such a small difference in passing distances does not significantly influence the objective acceptability of the opportunity. It is likely that a substantial part of the difference between the two curves is related to impedance. However, it is also possible that drivers were reluctant to pass lead cars traveling at higher speeds because the passing maneuver itself may seem more hazardous to drivers when speeds are high.

Passing Performance—Figure 15 shows mean passing and decision times, for those drivers who accepted sight-distance-limited passing opportunities, as a function of the sight distance. The equivalent nighttime OC-limited data are also plotted for comparative purposes, but it should be recognized that the abscissa scale is sight distance for the sight-distance-limited data and passing-opportunity distance (LC-OC distance) for the OC-limited data. Decision times for sight-distance-limited passes were consistently higher (from 0.9 to 10.5 sec) than for OC-limited passes. In fact, at sight distances between 3,500 and 4,000 ft, average decision times (14 sec) were greater than average passing times (12.4 sec). As most of the long (greater than 3,000 ft) sight-distance-limited passing opportunities were observed when traffic was light, it is possible that the long decision times arose because the drivers were not concerned about missing a passing opportunity.

Figure 15 shows that drivers passed less quickly by 1 to 6 sec when no OC was in sight. Although passing times in sight-distance-limited passes increased somewhat with increasing sight distance, the slope of this effect was not as strong as was the case in OC-limited passes, and even in passes that started with less than 1,000 ft of sight distance the average passing time was 10 seconds. Perhaps drivers are not as motivated by the sight of diminishing sight distance as they are by the sight of a rapidly approaching oncoming car.

CONCLUSIONS

Under both day and night conditions, the likelihood that a driver will accept an OC-limited passing opportunity increases as the passing-opportunity distance increases. At a given passing-opportunity distance, passing likelihood decreases with increasing LC speed. Drivers were both more conservative and more variable in their passing decision-making at night than they were during the day. The day threshold passing-opportunity distance was about 2,050 ft and at night it was about 2,800 ft. The standard deviation of the passing frequency distributions was estimated to be 950 ft during the day and 1,300 ft at night. Only part of this variability is due to distance judgment. It is likely that a substantial portion is caused by individual differences between drivers in what they consider to be an acceptable passing opportunity. Variability caused by individual differences appears to be greater at night than during the day. It was argued that the acceptance of truly hazardous passing opportunities is a consequence of small errors of judgment made by drivers who have short passing-opportunity distance thresholds rather than of large errors made by more conservative drivers.

In OC-limited passes, decision time was slightly but significantly less at night than during the day and, under both day and night conditions, decreased with decreasing passing-opportunity distance. Passing times also decreased with passing-opportunity distance to a minimum of 5.5 to 6 sec. There was little difference between day and night conditions, and at short passing-opportunity distances drivers used the full performance potential of their vehicles to pass during the night as well as during the day. This suggests that on the highway studied, nighttime visibility conditions did not have a strong cautionary effect on the dynamics of the passing maneuvers.

In sight-distance-limited passes at night, passing likelihood increased with increasing passing-opportunity distance. The threshold passing-opportunity distance was about 1,750 ft. Fifteen percent of the passing-opportunity sight distances less than 1,000 ft were accepted despite the fact that, had an OC appeared, the resulting OC-limited pass would have presented a greater hazard than most drivers would ordinarily accept. It was hypothesized that at night OC headlights served as a cue to the presence or absence of oncoming traffic beyond the sight-distance zone. Passing times in sight-distance-limited passes were considerably higher than those observed in OC-limited passes and did not decrease substantially as the sight distance decreased. This was attributed to the greater sense of urgency occasioned by the sight of a rapidly approaching OC.

ACKNOWLEDGMENTS

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Editor's Note: A list of references was not provided with the paper.

Wrong-Way Driving Accidents Are Reduced

THOMAS N. TAMBURRI, California Division of Highways

This report describes the circumstances surrounding wrong-way driving on California freeways and expressways. It provides some insight into the biographical background of the wrong-way driver. Data concerning observed wrong-way driving incidents during three separate 9-month periods were furnished by traffic enforcement officers. In addition, 168 wrong-way drivers were interviewed.

The effectiveness of various preventive devices installed on California freeways and expressways was tested. The before and after study method was used, using both incidents of wrong-way driving and wrong-way driving accidents. Reported incidents were also used to measure the efficacy of various off-ramp types in preventing wrong-way entry.

•THERE ARE in California 2,600 miles of freeways and 600 miles of expressways. These highways carried approximately 35 billion vehicle-miles of travel in 1968, a third of all travel in California. With this large amount of travel, some careless or inattentive motorist occasionally finds himself driving on the wrong roadway.

Before devices described in this report were installed, 69 persons were killed (1965) in freeway wrong-way driving accidents—10 percent of the freeway fatalities. Sixty-nine were killed in 1968 also, but if the mileage wrong-way fatality rate had continued, 150 persons would have died in such accidents in 1968.

As early as 1960, it became apparent that wrong-way driving was to become a significant factor in freeway and expressway safety. A pilot study called Phase I (1) in 1961 indicated that pavement arrows might help. Small white arrows were painted at the cross-street terminal of all off ramps. A second, more comprehensive study called Phase II (4) indicated that the arrows reduced wrong-way driving 17 percent, with the reduction occurring in daylight hours.

More significantly, the Phase II study gave considerable insight on where, when, and how the driver was making his error. One of the primary findings was that approximately half the wrong-way entries to freeways and expressways were occurring at off ramps and at expressway grade intersections. As a result, the following preventive devices were installed during 1965 and the early part of 1966:

1. At Off Ramps (3 devices)—(a) A pair of 36- by 21-in. white-on-red WRONG WAY signs (Fig. 1) with (b) a pair of 36- by 36-in. black-on-white DO NOT ENTER signs (Fig. 1) and (c) 24-ft white painted pavement arrows (Fig. 2).
2. At On Ramps (2 devices)—(a) A pair of 36- by 21-in. white-on-green FREEWAY ENTRANCE signs (Fig. 3) and (b) white painted pavement arrows to be visible from the local road. Figure 4 shows the entire package for the on and off ramps.
3. At Transitions From Undivided Roads to Freeways or Expressways (4 devices)—(a) A large 48- by 72-in. black-on-white KEEP RIGHT sign (Fig. 5) in the median gore facing approach traffic; (b) a 48- by 48-in. black-on-white DIVIDED ROAD sign; (c) a pair of oversize 72- by 72-in. black-on-white DO NOT ENTER signs with oversize

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72- by 22-in. white-on-red WRONG WAY signs; and (d) several 24-ft long white painted pavement arrows facing both the wrong-way driver and indicating the correct path to follow.

4. Transitions From Freeways to Expressways (2 devices)—The oversize DO NOT ENTER and WRONG WAY signs at the first median crossover or grade intersection before the freeway.

5. On Expressways (1 device)—The large painted pavement arrows at all grade crossings and at median crossovers.

6. On Freeway Lanes (1 device)—Raised retroreflective lane markers on all freeways and on most expressways (these markers reflect white to right-way drivers and red to wrong-way drivers).

Figure 1. Off-ramp black-on-white sign augmented with white-on-red sign.

In addition to these devices that were installed statewide, special devices (Fig. 6) were installed in District 04, comprising the nine counties around San Francisco Bay. These were white-on-red 60- by 36-in. GO BACK—YOU ARE GOING WRONG WAY signs immediately before (with respect to the wrong-way driver) the ramp-freeway nose, and raised red retroreflective marker arrows on each off ramp. All signs, arrows, and pavement markers were reflectorized. Specifications for most of the signs and arrows are included in another report (4).

It was hypothesized that the special signs would cause a further reduction in both day and night accidents and the special arrows would have an additional benefit at night only. After the devices were installed, Phase III was started. Its objectives were (a) to determine the effectiveness of the remedial measures, (b) to identify off-ramp types least susceptible to wrong-way entry, (c) to determine what specific ramp and cross-street geometry and traffic control measures are most effective in preventing wrong-way entry, and (d) to obtain more data on wrong-way driver characteristics and the circumstances surrounding the driver's mistake.

Figure 2. Newer style of white pavement arrow.

Figure 3. On-ramp white-on-green freeway entrance signs.

As a part of each phase, observed incidents of wrong-way driving were recorded on special reports by enforcement officers of the California Highway Patrol and the police of Los Angeles, San Diego, Long Beach, and Riverside (except that only the highway patrol reported during Phase I). Each incident study lasted 9 months, except that the California Highway Patrol was requested to start a month earlier in the last phase to test procedures used in a special nine-county wrong-way driver interview study. In addition, research personnel created an incident report for each accident report received without an incident form.

Driver interviews were conducted by specially trained driver-improvement analysts. For each of the interviewees and for at-fault drivers involved in accidents for a 1-year period, additional biographical data were obtained from accident and driver-violation records and from criminal and medical records.

A movie camera survey of 90 ramps to determine the effect of ramp and cross-street geometry and traffic control measures is still under way (March 1969) and will be reported later.

INCIDENT STUDIES

The following number of wrong-way driving incidents were reported for the three phases:

Phase	Freeways	Expressways	Conventional Roads	Total
I	312	187	243	742
II	451	167	97	715
III	379	79	66	524
Total	1,142	433	406	1,981

Figure 4. Example of both types of signs: off-ramp wrong-way signs and on-ramp freeway entrance signs.

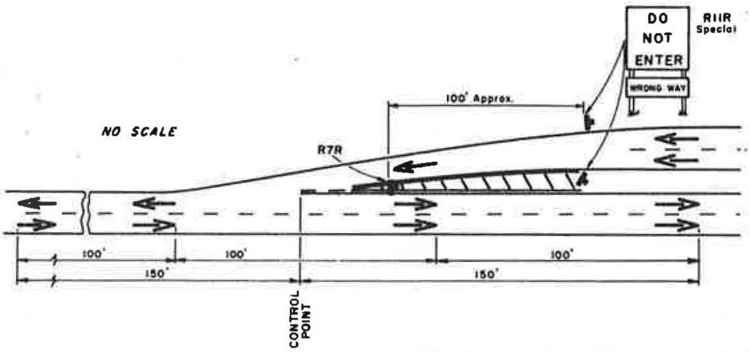


Figure 5. Transition area from undivided roads to freeways or expressways.

Figure 6. Special devices illuminated by wrong-way vehicles during the nighttime on off ramps. These include white-on-red GO BACK—YOU ARE GOING WRONG WAY signs, DO NOT ENTER—WRONG WAY signs, and raised red retroreflective marker arrows.

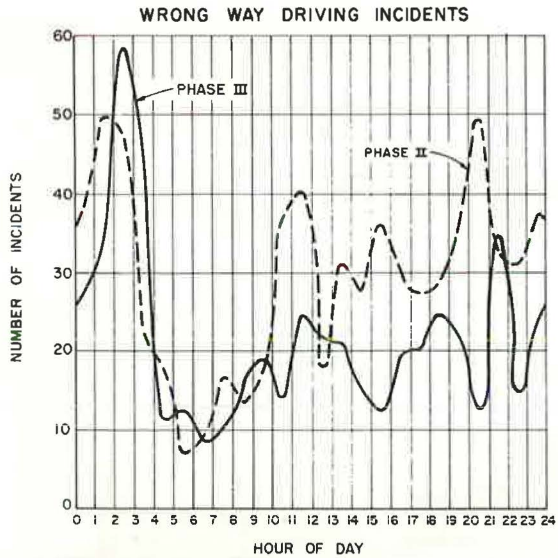


Figure 7. Hourly distribution of wrong-way driving incidents.

In Phase I, conventional roads were not classified as to weather, sobriety, time, or other conditions. The officers were not required to report incidents on conventional roads but some reporting was done anyway. Where specific data were available, they were included with the freeway and expressway information.

The 524 reports received in the Phase III study were compared with 1,214 incident reports of the Phases I and II studies to see if changes in wrong-way driving population characteristics had occurred because of the preventive measures instituted immediately before Phase III. The 243 reports received on conventional roads in Phase I could not be used in the comparison because of incomplete data. The comparisons are listed below:

1. Time of Day—There was a decrease in wrong-way driving except for the 2:00 a.m. to 4:00 a.m. period. Figure 7 shows the hourly distribution of the incidents.

2. Monthly Distribution—This comparison is not shown because identical calendar months were not used for the three phases.

3. Day of Week—There was a slight increase in the percentage of wrong-way driving on the weekends (Friday, Saturday, and Sunday):

	Phases I and II		Phase III	
Day of Week	No.	Percent	No.	Percent
Sunday	196	16.2	106	20.3
Monday	157	13.0	72	13.7
Tuesday	166	13.7	55	10.5
Wednesday	138	11.4	60	11.4
Thursday	189	15.6	57	10.9
Friday	165	13.6	82	15.6
Saturday	199	16.5	92	17.6
	1,210	100.0	524	100.0
Not stated	4		0	
	1,214		524	

4. Sex—There was no change in the distribution by sex:

	Male		Female		Not Stated
Phase	No.	Percent	No.	Percent	No.
I and II	971	80	242	20	1
III	413	79	109	21	2

5. Weather—There was no change by weather condition:

Weather	Phases I and II No.	Phases I and II Percent	Phase III No.	Phase III Percent
Clear	912	79.3	391	79.9
Cloudy	133	11.6	62	12.7
Raining	61	5.3	21	4.3
Snowing	5	0.4	0	0.0
Fog	35	3.0	15	3.1
Other	5	0.4	0	0.0
	1,151	100.0	489	100.0
Not stated	63		35	
	1,214		524	

6. Light Condition—There may have been a slight proportional increase of wrong-way driving at night:

Light Condition	Phases I and II No.	Phases I and II Percent	Phase III No.	Phase III Percent
Daylight	522	43.1	199	39.1
Dusk or dawn	33	2.7	14	2.8
Dark, street lights	271	22.4	150	29.4
Dark, no street lights	385	31.8	146	28.7
	1,211	100.0	509	100.0
Not stated	3		15	
	1,214		524	

7. Sobriety—In terms of percentage, there has been a considerable increase in the amount of drinking in the wrong-way driving population. Most of the Phase III drivers (54 percent) had been drinking vs 38 percent of the drivers in Phases I and II.

8. Traffic Conditions—There was a large increase in the percentage of wrong-way incidents occurring on facilities with light traffic. This is probably due to the many miles of rural freeways completed in the time period between the two studies:

Traffic Volumes	Phases I and II No.	Phases I and II Percent	Phase III No.	Phase III Percent
Light	507	44.3	225	57.1
Moderate	545	47.7	131	33.2
Heavy	91	8.0	38	9.7
	1,143	100.0	394	100.0
Not stated	71		130	
	1,214		524	

9. Roadway Use—The only change appears to be an increase in the "had-been-drinking" driver in each category:

Driver Use of Road	Phase II No.	Phase II Percent	Phase II Percent Who Had Been Drinking	Phase III No.	Phase III Percent	Phase III Percent Who Had Been Drinking
Regularly	146	25.0	53.7	111	28.6	65.7
Occasionally	132	22.6	39.4	83	21.4	49.4
Rarely	158	27.1	32.3	105	27.1	43.7
Never before	148	25.3	26.4	89	22.9	29.2
	584	100.0	46.9	388	100.0	57.0
Not stated	130			136		
	714			524		

10. Age and Sobriety—The mean age was 46.4 for the Phase III drivers and 47.6 for Phase II. Table 1 shows the amount of wrong-way driving by driver age. The number of registered drivers and average miles driven in each age group was introduced to determine a relative index of wrong-way driving based on travel exposure. The relative amount of wrong-way driving decreased, as age increased, to a low point (30 to 39 years) and then increased. Generally, younger drivers are less involved, and drivers over 50 are excessively involved on a mileage basis. On the basis of frequency, the driver under 50 is primarily involved.

Table 2 shows by age group the percentage of wrong-way drivers who had been drinking. The percentage increased in all age groups. Figure 8 summarizes the age distribution of registered driver-miles (exposure), total wrong-way drivers, and had-been-drinking wrong-way drivers for Phase III.

DRIVER INTERVIEWS

Phase III wrong-way driving incident reports (224 incidents) for all drivers residing in a nine-county area (Alameda, Contra Costa, Los Angeles, Riverside, Sacramento,

TABLE 1

WRONG-WAY INCIDENTS BY DRIVER AGE
(Freeway and Expressways—Phase III only)

Age	Incidents No.	Incidents Percent	Registered Drivers[a] No. ($\times 10^6$)	Registered Drivers[a] Percent	Average Annual Miles Driven[b]	Exposure (BVM)[c]	Wrong-Way Rate
16 to 20	19	4.2	0.922	9.3	7,300	5.05	3.76
21 to 24	31	6.8	0.892	9.0	13,700	9.17	3.38
25 to 29	41	9.0	1.121	11.3	15,200	12.77	3.21
30 to 39	75	16.4	2.241	22.6	15,900	26.72	2.81
40 to 49	89	19.5	2.122	21.4	15,000	23.87	3.73
50 to 59	79	17.3	1.438	14.5	13,300	14.34	5.51
60 to 69	65	14.3	0.803	8.1	10,400	6.26	10.38
70 and over	57	12.5	0.377	3.8	6,900	1.95	29.23
Unknown	2	–	–	–	–	–	–
TOTAL	458	100.0	9.916	100.0	13,400[d]	100.13	4.55[d]

[a]Research and Statistics Section, California Department of Motor Vehicles.
[b]Albert Burg (8, p. 30).
[c]Nine-month exposure equals number of registered drivers times average annual miles driven times 0.75.
[d]Average, not total.

TABLE 2

SOBRIETY BY AGE GROUPS
(All Incidents)

Age Group	HBR[a] No.	HBR[a] Percent	Sober No.	Sober Percent	Total No.	Total Percent	Percent Who Had Been Drinking: Three Phases	Percent Who Had Been Drinking: Phase III	Percent Who Had Been Drinking: Phases I and II[b]
16 to 29	138	19.9	161	16.7	299	18.0	46.1	65.2	34.6
30 to 39	187	27.0	117	12.1	304	18.3	61.5	69.2	58.9
40 to 49	181	26.2	152	15.7	333	20.1	54.4	65.6	49.8
50 to 59	124	17.9	173	17.9	297	17.9	41.8	48.3	39.1
60 to 69	49	7.1	189	19.5	238	14.4	20.6	41.6	12.7
70 and over	13	1.9	175	18.1	188	11.3	6.9	9.8	5.8
Unknown	—	—	—	—	79	—	—	—	—
TOTAL	692	100.0	967	100.0	1,738	100.0	41.7	54.0	36.7

[a]Had been drinking.

[b]From Tamburri (5).

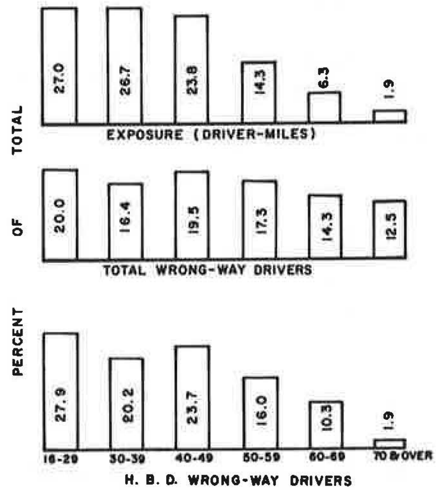


Figure 8. Various distributions of Phase III wrong-way driving incidents by age group.

Santa Barbara, Solano, and Ventura) were given to the California Department of Motor Vehicles. Five specially trained driver-improvement analysts interviewed 168 of these drivers. The remaining 56 in the subsample had left the state, did not appear at their scheduled appointment, or were deceased. (Eight drivers were killed in accidents resulting from the initiating incident.)

Biographical data (age, sex, driving experience, annual miles driven, and occupation) were obtained and a vision acuity test (Orthorater) and a color blindness test (Ishihara charts) were given. The interviewers reviewed the accident and driving violations records of these individuals. Also, the interviewers determined whether the Department of Justice, Bureau of Criminal Statistics, had criminal records for these drivers and whether the drivers had physical and mental illness records available at the California Department of Public Health. Additional data on the 56 drivers in the subsample who were not interviewed were obtained from Motor Vehicle records and accident reports on wrong-way accidents resulting from the initiating incident.

To determine whether the subsample of 224 incidents was representative of the 524 total Phase III incidents, the average age, the distribution by age, the distribution by sex, and the age distribution of sobriety of the subsample were compared to the full sample. In general, these variables were very similar, and it can be assumed that the subsample represented the full sample.

The following were determined from the interview and other available sources:

1. Driving Experience—Driving experience ranged from none to 66 years and averaged 25.6 years:

Age Group	Years of Driving
16 to 29	7.3
30 to 39	14.9
40 to 49	26.8
50 to 59	33.8
60 to 69	43.1
70 to 79	42.8
80 and over	40.5

2. Annual Miles Driven—Annual miles driven ranged from 1,000 to 100,000, averaging 15,000 miles:

Age Group	Annual Mileage
16 to 29	14,400
30 to 39	18,500
40 to 49	16,200
50 to 59	16,000
60 to 69	14,900
70 to 79	8,300
80 and over	13,000

3. Occupation—The largest group is the blue-collar worker. There were only nine professional drivers. Another surprisingly small category was the military (three):

Occupation Type	Number of Persons
Professional	13
White collar	36
Blue collar	88
Retired	23
Miscellaneous	20
Unknown	44
	224

4. Vision Acuity—Column A in the table below shows the visual acuity of the interviewees when tested without glasses. This includes those persons who normally would wear glasses. Column B shows the vision data adjusted to reflect the acuity scores when individuals who normally wear glasses were tested with their glasses:

	Number of Drivers	
Test Score	A	B
20/10	2	2
20/20	50	68
20/30	51	58
20/40	27	27
20/50	10	2
20/60	2	2
20/70	3	0
20/100	5	0
20/200	1	0
Not tested	73	65

If 20/40 is considered "normal," only a small percentage of the drivers had any visual difficulty by either column A or column B standards.

5. Medical and Mental History—Forty-one of the interviewees had a history of medical problems. Eighteen of these had a history of alcoholism. Ten of the interviewees had a known mental health history.

6. Status of Drivers' Licenses—Twenty-two of the 224 drivers had driving restrictions (six suspended licenses, five revoked, four on probation, six no licenses, one restricted license) at the time of the wrong-way incident.

7. Accident Records—The 224 drivers were involved in 135 accidents in the 3 years immediately preceding the wrong-way driving incident. Included in the 135 accidents were 44 wrong-way driving accidents that brought the interviewee to the attention of the Department of Motor Vehicles. This left a net of 91 accidents before the wrong-way driving accidents.

The average California driver has 0.20 accident per 3-year period (9). Because some of the 224 drivers did not have full 3-year driving records, the actual number of recorded years of driving for these operators was used to permit an unbiased comparison. The result was 210 equivalent 3-year driving periods for the 224 drivers. Using the 91 accidents and the 210 equivalent 3-year periods gave a rate of 0.43 accident per 3-year driving record for the subsample. This is over twice the accident rate of the average California driver.

8. Motor Vehicle Violations—The 224 drivers had 360 moving violations in the 3-year period immediately preceding the wrong-way incident. Fifty-seven drivers had three or more violations. In addition, there were 97 nonmoving violations.

California drivers average 0.80 violation per 3 years (9). The 360 moving violations and the 210 equivalent 3-year driving periods were used to obtain an average of 1.71 violations per 3-year period. The wrong-way driver, therefore, committed approximately twice as many driving violations as the average California driver.

9. Nondriving Convictions—The Bureau of Criminal Identification and Investigation (CII) of the Justice Department furnished data on each driver in the subsample who had a criminal record. Ninety motorists (41 percent) had records, totaling 465 convictions. The distribution of drivers by number of convictions is listed below. Although no definite data could be found, it is felt that the percentage of the general driving population with nondriving conviction records is considerably less than 41 percent:

Number of Nondriving Convictions	Number of Drivers
0	132
1	24
2	18
3	10
4	10
5	3
6	6
7	3
8	1
9	0
10 or more (33 maximum)	15
Unknown	2

WRONG-WAY DRIVERS INVOLVED IN ACCIDENTS

To obtain more specific information concerning the at-fault driver involved in wrong-way driving accidents, the identities of the at-fault drivers in wrong-way driving accidents on California freeways and expressways from January through September 1965 were determined. Some accidents were caused by wrong-way drivers not actually

TABLE 3

AGE DISTRIBUTION

Age Group	All California Drivers	Drivers—All Types of Accidents	At-Fault Drivers, Wrong-Way Accidents[a]
Under 21	4.8	8.5	4.4
21 to 30	20.4	23.6	20.3
31 to 40	24.9	23.8	26.5
41 to 50	23.0	20.7	21.2
51 to 60	15.2	13.4	16.0
61 to 70	8.5	7.3	7.1
70 and over	3.2	2.7	4.5
TOTAL	100.0	100.0	100.0
Mean age	41.7	39.6	42.3

[a]January 1 through September 30, 1965.

involved in the collision and other wrong-way drivers sustained only slight vehicle damage. Some of these drivers were able to flee the scene before their identity could be determined.

From 153 accidents, 137 names were obtained. Records for 136 of these drivers were found. The 3-year records of this group indicate that their accident and violation experiences were approximately the same as the group involved in only incidents, but were substantially higher than the average driver in both categories. However, there were some discrepancies in the cutoff date of the furnished records with regard to the accident and violation that initiated the selection. Therefore, the computed rates are subject to some question and are not included in the report.

Department of Justice CII records were investigated for the 136 wrong-way accident drivers. These drivers had been arrested on criminal charges a total of 360 times. One driver had been arrested 42 times and his driver's license had expired in 1951. Nineteen drivers had been arrested on criminal charges five or more times. The arrests and convictions ranged from murder, assault with a deadly weapon, robbery, and sex crimes to drunk and disorderly conduct and vagrancy. Seventy-two drivers (53 percent) had criminal records. The percentage having criminal records is considerably higher for wrong-way drivers involved in accidents (53 percent) than for the general wrong-way driving population (41 percent).

Table 3 shows the age distribution for wrong-way drivers involved in accidents, drivers involved in all types of accidents, and a large sample of all California licensed drivers (9). Only wrong-way drivers (113) involved in accidents who had full 3-year driving records were used in this comparison, thus permitting an unbiased comparison with the referenced data (9). The mean age of the 113 wrong-way accident drivers is approximately the same as the mean age of all drivers, and their age distribution is approximately the same as that of drivers involved in all types of accidents. However, the mean age of the wrong-way accident drivers is approximately 5 years younger than the mean age of 46.4 for all wrong-way drivers.

Distribution by sex of the 113 at-fault drivers confirms that the wrong-way driving problem is grossly biased toward the male driver. Women held 41 percent of all valid 3-year licenses in the California Department of Motor Vehicles study (9). They constituted only 21 percent of wrong-way drivers in the incident study, and were only 10 percent of the at-fault drivers in wrong-way accidents. The fact that wrong-way accidents occur mostly at night may account for the low ratio of women. Another possible reason is that a considerably smaller percentage of women than of men had been drinking. In the incident study, 61 percent of the male drivers had been drinking and only 29 percent of the female drivers had.

BEFORE AND AFTER COMPARISONS OF INCIDENTS

To determine wrong-way driving trends and test the remedial measures' effectiveness, a before and after comparison was made between wrong-way driving rates during Phase II (July 15, 1963, to April 14, 1964) and Phase III (June 1, 1966, to February 23, 1967). The rates were determined from the incident reports furnished by the enforcement officers.

For freeways, the rates compared were the number of incidents per 100 ramp-years. For expressways, the rates used were the number of incidents per year per 100 miles.

In the case of freeways, various exposure variables were considered—number of freeway miles, amount of travel (vehicle-miles), number of off ramps, and number of trips. It was felt that the amount of wrong-way driving should increase with an increase in these four variables, especially in the number of trips, because each trip presents a distinct opportunity to drive the wrong way. However, the number of trips for each ramp type or specific location was not available except at very great expenditure of time and effort, and the number of trips by light condition was not available at any cost. Therefore, the remaining variables with the least increase between the two studies (number of off ramps) was used. This would indicate the most conservative improvement.

In the case of expressways, the number of entry points (grade crossings and expressway ends) were not readily available, so only miles and vehicle-miles were considered. Each increased approximately by the same amount, and the measure of miles was chosen. The rates of observed wrong-way driving were reduced 60 percent on freeways and 69 percent on expressways (Tables 4 and 5).

Because special additional devices were installed in District 04, it is shown separately in Tables 4 and 5. In spite of the additional devices, District 04 experienced a lesser improvement (a 47 percent reduction vs a 64 percent for the rest of the state). However, in District 04 there was a greater percentage reduction in daytime wrong-way entries, whereas the District 04 nighttime reduction was only half as large as the rest of the state. (The changes in incident frequencies were tested for significance using the chi-square method as described in the Appendix.)

On expressways (no special devices), District 04 improvement was approximately the same as in the rest of the state. On certain freeways and expressways in District 04 during the after period, the highway patrol was involved in an experiment (Operation 500) to test the effect of increased patrolling on accidents. The level of arrests more than doubled and a comparable increase in the level of observed wrong-way driving probably occurred. It is estimated that 17 incidents were observed that would have

TABLE 4

RATE OF WRONG-WAY INCIDENTS—FREEWAYS
(Not Adjusted for Operation 500)

Period	No. Ramps	No. of Incidents per 100 Ramp-Years			Percent Dark
		Day	Dark	Total	
District 04					
Before	453	(31) 9.1[a]	(71)20.9	(102)30.0	71
After	607	(14) 3.1	(59)12.9	(73)16.0	81
Percent change rate	+34	-67	-38	-47	
Chi-square value		16.93 S[b]	7.10 S	16.62 S	
Other Districts					
Before	1,801	(133) 9.8	(212)15.7	(345)25.5	61
After	2,467	(79) 4.2	(91) 4.9	(170) 9.2	54
Percent change rate	+37	-57	-69	-64	
Chi-square value		36.5 S	97.5 S	38.3 S	
All Districts					
Before	2,254	(164) 9.7	(283)16.7	(447)26.5	63
After	3,074	(93) 4.0	(150) 6.5	(243)10.5	62
Percent change rate	+36	-59	-61	-60	
Chi-square value		39.3 S	94.6 S	144.7 S	

[a]Numbers within parentheses are those of incidents. [b]S—significant.

TABLE 5

RATE OF WRONG-WAY INCIDENTS—EXPRESSWAYS
(Not Adjusted for Operation 500)

Period	No. Miles	No. of Incidents per 100 Mile-Years			Percent Dark
		Day	Dark	Total	
District 04					
Before	110	(10)12.1[a]	(17)20.6	(27)32.8	63
After	89	(5) 7.5	(1) 1.5	(6) 9.0	17
Percent change rate	-19	-38	-93	-73	
Chi-square value		0.42 NS[b]	9.76 S[c]	8.20 S	
Other Districts					
Before	695	(73)14.0	(67)12.9	(140)27.0	48
After	645	(24) 5.0	(17) 3.5	(41) 8.5	42
Percent change rate	-7	-65	-73	-68	
Chi-square value		19.35 S	25.25 S	45.8 S	
All Districts					
Before	805	(83)13.8	(84)13.9	(167)27.7	50
After	734	(29) 5.3	(18) 3.3	(47) 8.6	38
Percent change rate	-9	-62	-76	-69	
Chi-square value		20.93 S	37.10 S	57.0 S	

[a]Numbers within parentheses are those of incidents. [b]NS—not significant.
[c]S—significant.

gone undetected on freeways (12). Deducting the "extra" 17 incidents gives an after rate of 11.9 incidents per 100 off-ramp years, a reduction of 60 percent, which approximates the 64 percent experienced by the other districts. No adjustment was made for the expressways because there were only six expressway incidents in District 04 in the after period.

Tables 6 and 7 show the number of incidents in Phases II and III by location of wrong-way origin. Incidents are subtotaled by locations with preventive devices during Phase III (off ramps and transitions) and locations where the preventive devices are not applicable (U-turns and across median).

TABLE 6

WRONG-WAY DRIVING INCIDENTS BY LOCATION OF POINT OF ORIGIN—FREEWAYS

Points of Origin	Phase II		Phase III		Percent Change
	No.	Percent	No.	Percent	
With Preventive Devices in Place During Phase III					
Entered freeway by off ramp	165	48.6	91	54.1	-45
Made U-turn from off ramp (right way on freeway)	13	3.8	1	0.6	-92
Entered at transition from expressway	0	0.0	0	0.0	0
Entered at transition from two-lane undivided road	0	0.0	5	3.0	—
Subtotal	(178)	(52.5)	(97)	(57.7)	(-46)
Without Preventive Devices in Place During Phase III					
Made U-turn in traffic lanes	71	20.9	38	22.6	-47
Drove across median	17	5.0	4	2.4	-77
Other U-turns on off or on ramps	10	3.0	14	8.3	+40
Made U-turn from on ramp (wrong way on freeway)	38	11.2	9	5.4	-76
Made U-turn into on ramp (right way on freeway)	25	7.4	6	3.6	-76
Subtotal	(161)	(47.5)	(71)	(42.3)	(-56)
Known origins	339	100.0	168	100.0	-50
Origins unknown	111		75		-32
TOTAL	450		243		-46

TABLE 7

WRONG-WAY DRIVING INCIDENTS BY LOCATION OF POINT OF ORIGIN—EXPRESSWAYS

Points of Origin	Phase II		Phase III		Percent Change
	No.	Percent	No.	Percent	
With Preventive Devices in Place During Phase III					
Entered at intersection (median opening)	67	47.2	21	61.7	- 69
Enter at undivided road transition	7	4.9	0	0.0	-100
Drove through median opening (no intersection)	35	24.7	0	0.0	-100
Subtotal	(109)	(76.8)	(21)	(61.7)	(-81)
Without Preventive Devices in Place During Phase III					
Drove across median	4	2.8	0	0.0	-100
Made U-turn	26	18.3	9	26.5	- 65
Other (driveways and ends of expressways)	3	2.1	4	11.8	+ 33
Subtotal	(33)	(23.2)	(13)	(38.3)	(-61)
Known origins	142	100.0	34	100.0	- 76
Origins unknown	25		13		- 48
TOTAL	167		47		- 72

The number (not rated) of wrong-way driving entries at freeways was reduced approximately 50 percent. There was a somewhat greater decrease in incidents originating at locations without preventive devices. There may be several reasons for this result, such as (a) the motorist is more aware of the problem because of the frequently observed control devices, (b) publicity given this problem in California, and (c) motorists becoming better freeway drivers. Wrong-way entry at expressways was reduced 72 percent with a greater reduction (81 percent) at locations with the devices than locations without devices (61 percent).

Tables 8 and 9 show the light condition for the incidents of Phases II and III at those locations with preventive measures and locations where wrong-way origins could not be controlled by the preventive measures. Locations with preventive measures showed a considerably greater reduction at night. As indicated later, the reduction in wrong-way driving accidents was considerably greater in the fatal category, perhaps because of the greater reduction in nighttime wrong-way driving when accidents are more severe. It appears, then, that the preventive measures on freeways were more effective

TABLE 8

LIGHT CONDITIONS FOR WRONG-WAY DRIVING INCIDENTS ORIGINATING AT LOCATIONS WITH PREVENTIVE DEVICES—FREEWAYS

Light Condition	Phase II		Phase III		Percent Change
	No. of Incidents	Percent	No. of Incidents	Percent	
Daylight	64	36.0	49	50.5	-23
Dawn and dusk	8	4.4	4	4.1	-50
Dark, street light	64	36.0	30	30.9	-53
Dark, no street light	42	23.6	14	14.4	-67
Subtotal, dark	(114)	(64.0)	(48)	(49.5)	-58
TOTAL	178	100.0	97	100.0	-46

TABLE 9

LIGHT CONDITIONS FOR WRONG-WAY DRIVING INCIDENTS ORIGINATING AT LOCATIONS WHERE USE OF PREVENTIVE MEASURES NOT APPLICABLE—FREEWAYS

Light Condition	Phase II		Phase III		Percent Change
	No. of Incidents	Percent	No. of Incidents	Percent	
Daylight	75	46.6	30	42.2	-60
Dawn and dusk	5	3.1	3	4.2	-40
Dark, street light	40	24.8	22	31.0	-45
Dark, no street light	41	25.5	16	22.6	-61
Subtotal, dark	(86)	(53.4)	(41)	(57.8)	-52
TOTAL	161	100.0	71	100.0	-56

at night. For freeway locations at which preventive measures do not apply, there seems to be no differential improvement by light conditions.

The red retroreflective raised pavement arrow was designed to reduce nighttime entry at off ramps. To determine its effectiveness, nighttime off-ramp entries in District 04 were compared with those of the remaining districts. Table 10 shows these comparisons adjusted for Operation 500. A lesser reduction occurred in District 04, so it appears that the red arrow is ineffective.

Daytime off-ramp entries were reduced considerably more in District 04 than in the rest of the state (80 percent vs 43 percent), indicating that the secondary sign (GO BACK—YOU ARE GOING WRONG WAY) is beneficial.

ACCIDENT ANALYSIS

The real function of the preventive devices is to reduce accidents, not wrong-way driving. Therefore, the best test of their success is a reduction in wrong-way driving accident frequency.

Wrong-way driving accident rates for the one year prior to installation were compared with the rates for the year after (Table 11). Changes in accident frequency were tested for significance using the chi-square method described in the Appendix.

For freeways, all accident and personal-involvement rates were reduced significantly except for property damage only and injury accident rates. The total accident rate was reduced approximately 30 percent and the fatal accident rate approximately 60 percent. The rates of persons killed and persons injured were reduced approximately two-thirds and one-third respectively. For expressways, only the personal injury and the total accident rates were reduced significantly.

TABLE 10

NUMBER AND RATES OF OFF-RAMP ENTRIES BY LIGHT CONDITION
(Incidents per 100 Ramp-Years)

Light Condition	Phase II				Phase III				Percent Change	
	District 04		Others		District 04		Others		District 04[a]	Others
	No.	Rate	No.	Rate	No.[a]	Rate[a]	No.	Rate		
Day	15	4.42	49	3.62	4	0.88	38	2.05	-80 S[b]	-43 S
Night	26	7.65	88	6.52	13	2.85	31	1.67	-63 S	-74 S
TOTAL	41	12.07	137	10.14	17	3.73	69	3.72	-69 S	-63 S

[a]Adjusted for Operation 500.

[b]S—significant at 0.05 level (chi-square test).

TABLE 11

WRONG-WAY DRIVING ACCIDENT RATES

Item	Accident Rates[a] PDO	Accident Rates[a] Injury	Accident Rates[a] Fatality	Accident Rates[a] Total	Personal Involvement Rates Killed	Personal Involvement Rates Injured	Exposure[a]
			Freeways				
Before	3.24 (73)[b]	3.64 (82)	1.77 (40)	8.65 (195)	3.64 (82)	11.09 (250)	22.54
After	2.44 (75)	2.99 (92)	0.68 (21)	6.11 (188)	1.27 (39)	6.77 (208)	30.74
Δ	- 0.80 (+2)	- 0.65 (+10)	- 1.09 (-19)	- 2.54 (-7)	- 2.37 (-43)	- 4.32 (-42)	
Percent Δ	-24.7 (+2.7)	-17.9 (+12.2)	-61.6 (-47.5)	-29.4 (-3.6)	-65.1 (-52.4)	-39.0 (-16.8)	
Chi-square value	2.72 NS[c]	1.47 NS	12.79 S[d]	11.30 S	31.07 S	27.85 S	
			Expressways				
Before	2.73 (22)	2.36 (19)	1.62 (13)	6.71 (54)	1.86 (15)	8.32 (67)	8.05
After	2.31 (17)	1.23 (9)	0.68 (5)	4.22 (31)	1.50 (11)	2.18 (16)	7.34
Δ	- 0.42 (-5)	- 1.13 (-10)	- 0.94 (-8)	- 2.49 (-23)	- 0.36 (-4)	- 6.14 (-51)	
Percent Δ	-15.4 (-22.7)	-47.9 (-52.6)	-58.0 (-61.5)	-37.1 (-42.6)	-19.4 (-26.7)	-73.8 (-76.1)	
Chi-square value	0.13 NS	2.18 NS	2.14 NS	3.82 S	0.13 NS	25.78 S	

[a]For freeways—per 100 ramp-years; for expressways—per 100 expressway miles.
[b]Numbers in parentheses are those of accidents or persons.
[c]NS—not significant.
[d]S—significant.

The special secondary signs were installed primarily to reduce the daytime accident rate and the reflective arrows to reduce the nighttime rate. Therefore, the freeway day and night accident rate changes were examined for District 04 and the remaining ten districts.

No significant daytime accident rate reductions occurred in District 04 or in the ten other districts (Table 12). This indicates that the secondary GO BACK—YOU ARE GOING WRONG WAY sign causes no additional accident reduction and contradicts the apparent large additional daytime incident reduction. This contradiction is due in part to the small daytime District 04 freeway accident sample size (six before and five after). Another factor masking the effect of all devices is the necessity to make the before and after comparisons using all accidents regardless of point of origin. The high severity of most wrong-way driving accidents and the high drinking involvement generally made it impossible for the investigating officer to determine where the wrong-way movement originated. Therefore, it was impractical to use only accidents originating at locations with preventive devices (off ramps and freeway ends). In the incident comparisons, the effect of various devices was determined by using only incidents originating at locations with the devices.

At night in District 04, the rates for both the number of persons killed and the number of persons injured were significantly reduced (Table 13). For the remaining ten districts, these two rates and the fatal accident and total accident rates were also significantly reduced. This would indicate that the special red arrows were of no additional benefit and confirms the findings of the incident analysis.

TABLE 12

WRONG-WAY DRIVING ACCIDENT RATES ON FREEWAYS—DAYTIME

Item	Accident Rates (per 100 ramp-years)				Personal Involvement Rates		Exposure per 100 Ramp-Years
	PDO	Injury	Fatality	Total	Killed	Injured	
District 04							
Before	0.88 (4)[a]	0.22 (1)	0.22 (1)	1.32 (6)	0.22 (1)	0.88 (4)	4.53
After	0.50 (3)	0.16 (1)	0.16 (1)	0.82 (5)	0.66 (4)	0.66 (4)	6.07
Δ	- 0.38 (-1)	- 0.06 (0)	- 0.06 (0)	- 0.50 (-1)	+ 0.44 (+3)	- 0.22 (0)	
Percent Δ	-43.1 (-25)	-27.3 (0)	-27.3 (0)	-37.9 (-16.7)	+200.0 (+300.0)	-25.0 (0)	
Chi-square value	0.15 NS[b]	0.02 NS	0.02 NS	0.24 NS	0.29 NS	0.01 NS	
All Other Districts							
Before	0.50 (9)	0.78 (14)	0.28 (5)	1.55 (28)	0.61 (11)	2.22 (40)	18.01
After	0.53 (13)	0.65 (16)	0.16 (4)	1.34 (33)	0.32 (8)	1.46 (36)	24.67
Δ	+ 0.03 (+4)	- 0.13 (+2)	- 0.12 (-1)	- 0.22 (+5)	- 0.29 (-3)	- 0.76 (-4)	
Percent Δ	+ 6.0 (+44.4)	-16.7 (+14.3)	-42.9 (-20.0)	-14.1 (+17.9)	-47.5 (-27.3)	-34.2 (-10.0)	
Chi-square value	0.02 NS	0.87 NS	0.22 NS	0.22 NS	1.35 NS	2.96 NS	

[a]Numbers in parentheses are those of accidents or persons. [b]NS—not significant.

TABLE 13

WRONG-WAY DRIVING ACCIDENT RATES ON FREEWAYS—NIGHTTIME

Item	Accident Rates (per 100 ramp-years)				Personal Involvement Rates		Exposure per 100 Ramp-Years
	PDO	Injury	Fatality	Total	Killed	Injured	
District 04							
Before	3.75 (17)[a]	3.31 (15)	1.77 (8)	8.83 (40)	2.87 (13)	12.58 (57)	4.53
After	2.80 (17)	3.29 (20)	0.66 (4)	6.75 (41)	0.66 (4)	6.92 (42)	6.07
Δ	- 0.95 (0)	- 0.02 (+5)	- 1.11 (-4)	- 2.08 (+1)	- 2.21 (-9)	- 5.66 (-15)	
Percent Δ	-25.3 (0)	- 0.6 (+33.3)	-62.8 (-50.0)	-23.6 (+2.5)	-77.0 (-69.2)	-45.0 (-26.3)	
Chi-square value	0.49 NS[b]	0.002 NS	1.96 NS	1.21 NS	6.49 S[c]	8.33 S	
All Other Districts							
Before	2.39 (43)	2.83 (51)	1.44 (26)	6.66 (120)	3.16 (57)	8.27 (149)	18.01
After	1.70 (42)	2.23 (55)	0.49 (12)	4.42 (109)	0.93 (23)	5.11 (126)	24.67
Δ	- 0.69 (-1)	- 0.60 (+4)	- 0.95 (-14)	- 2.24 (-11)	- 2.23 (-34)	3.16 (-23)	
Percent Δ	-28.9 (-2.3)	-21.2 (+7.8)	-66.0 (-53.8)	-33.6 (-9.2)	-70.6 (-59.6)	-38.2 (-15.4)	
Chi-square value	2.10 NS	1.30 NS	9.74 S	9.39 S	26.39 S	15.65 S	

[a]Numbers in parentheses are those of accidents or persons. [b]NS—not significant.
[c]S—significant.

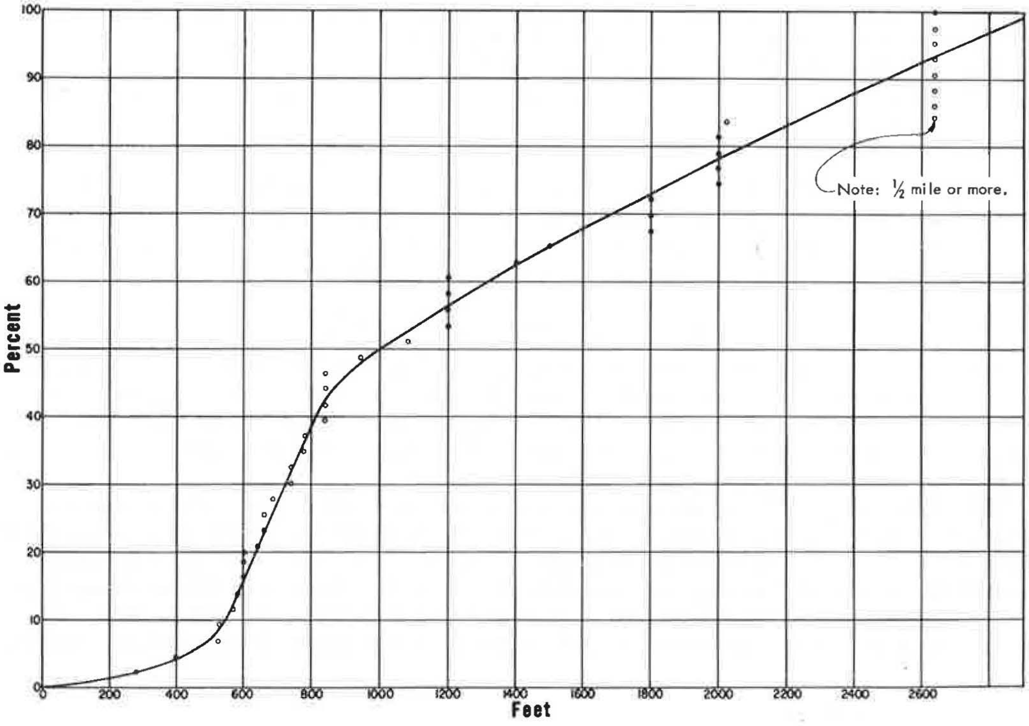


Figure 9. Sight distances available to the right-way driver vs the cumulative percent of the accidents.

DEATHS AND ACCIDENTS PREVENTED

Wrong-way accident rates for the before and after periods were also compared on the basis of billion vehicle-miles of travel. On freeways the exposures were 22.6 billion vehicle-miles before and 27.9 billion vehicle-miles after. The rate was reduced from 8.62 to 6.73 accidents per billion vehicle-miles (22 percent). On expressways the exposures were 4.3 billion vehicle-miles before and 3.9 billion vehicle-miles after. These accident rates were reduced from 12.61 to 7.95 accidents per billion vehicle-miles (37 percent).

Assuming that the number of accidents and persons injured or killed in the after period would have increased linearly with travel, it is estimated that the devices prevented 65 fatalities, 146 injuries, and 71 accidents.

EFFECT OF SIGHT DISTANCE

Motorists involved in wrong-way driving accidents may not be receiving adequate notice (because of restricted sight distance) to take evasive action. To evaluate this possibility, the sight distances at locations of all fatal and injury freeway accidents for a 1-year period were determined. Accidents in which sight distances were restricted by weather or traffic density and accidents occurring at ramps were culled out, thus leaving 45 out of an original sample of 115. The effect of median barriers, piers, abutments, and cut slopes on sight distance was considered. Figure 9 shows sight distances available to the right-way driver vs the cumulative percent of the accidents. (Many wrong-way drivers were too drunk to take evasive action.) Distances were based on a 3.75-ft eye height to headlights at a 2.0-ft height because most accidents occurred at night.

Half of the accidents occurred where sight distance was less than 1,000 ft. Sight distance needed by the right-way driver to avoid a collision can be rationalized as follows:

Rate of closure = 205 ft/sec (both wrong- and right-way vehicle at 70 mph)
Perception and brake reaction time = 2.5 sec (10, p. 135)
Minimum lane shift time = 3 sec (10, p. 347)
Total time required for evasion = 5.5 sec (assuming no correction by wrong-way driver)
Thus 5.5 sec times 205 ft/sec = 1,130 ft sight distance needed.

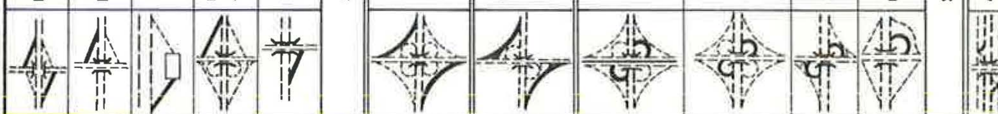
It appears that providing a 1,200-ft minimum sight distance (3.75-ft eye height to 2.0-ft headlight height) would permit sufficient notice to 60 percent of the right-way drivers for most of them to avoid a collision. These drivers now have less than 6 seconds to perceive, react, and evade the wrong-way vehicle.

EFFECT OF OFF-RAMP TYPE

During the three incident studies, there were 440 incidents where the off ramp of wrong-way entry could be positively identified. These incidents were classified by ramp type (Table 14). An inventory of off-ramp types was made using the midpoint of each study period. For each period and for the sum of the three periods, rates for each ramp type were determined (Table 14).

The wrong-way entry rates were 11.33 incidents per 100 ramp-years during the first study period, 9.36 for the second period, and 5.24 for the third. If it is assumed that the number of entries should be proportional to off-ramp-years, the expected distribution of the 307 wrong-way entries of the first two studies is 134 in Phase I and 173 in Phase II. The observed distribution was 149 in Phase I and 158 in Phase II. The difference between the expected and observed distributions is statistically signifi-

TABLE 14
WRONG-WAY ENTRIES BY OFF-RAMP TYPE



	DIAMONDS								LOOPS					
	FULL	HALF	VISTA PT. & REST AREAS	OTHER TYPES	ISOLATED RAMPS	SUB TOTAL	FULL CLOVER RT. TURN RAMP	HALF CLOVER RT. & LT. TURN	4 QUAD DIV. X RD.	4 QUAD UNDIV X RD.	2 QUAD	OTHER TYPES	SUB TOTAL	4 RAMPS
NO. OF INCIDENTS														
STUDY I [A]	23	3	0	19	0	45	1	9	0	0	7	0	7	1
STUDY II [A]	28	11	0	13	5	57	3	6	0	2	7	0	9	1
STUDY III [B]	36	11	0	5	8	60	8	4	0	1	4	0	5	1
TOTAL	87	25	0	37	13	162	12	19	0	3	18	0	21	4
NO. OF RAMPS														
STUDY I	330	116	0	142	21	609	108	109	124	13	72	0	209	3
STUDY II	438	168	0	196	34	836	141	144	153	16	90	0	259	4
STUDY III	708	215	13	261	47	1244	186	237	183	30	121	2	336	5
TOT. EXPOSURE (100 Ramp-Yrs.)	11.66	3.92	0.11	4.71	0.81	21.20	3.42	3.87	3.60	0.47	2.22	0.02	6.31	9.
ENTRY RATES (Incid./100 Ramp-Yrs)														
STUDY I	9.27	3.45	NA	17.82	0.00	9.85	1.23	11.00	0.00	0.00	12.97	NA	4.47	5.
STUDY II	8.51	8.74	NA	8.83	19.61	9.08	2.84	5.56	0.00	16.70	10.37	NA	4.63	3.
STUDY III	6.10	6.15	0.00	2.30	20.43	5.79	5.16	2.03	0.00	4.00	3.96	0.00	1.78	3.
TOTAL	7.46	6.37	0.00	7.86	16.04 [C]	7.64	3.51 [C]	4.91 [C]	0.00 [C]	6.38	8.10	0.00	3.33 [C]	4.

A) NINE MONTHS B) TEN MONTHS C) ENTRY RATE IS SIGNIFICANTLY DIFFERENT FROM THE AVE. (7.91) AT THE 005 LEVEL cant at the 0.10 level (χ^2 at 1 df = 2.77 if P < 0.10; for explanation of chi-square method throughout equations, see the Appendix). As previously reported (4), it is believed that the small, white pavement arrows painted on all off ramps between the first and second incident studies had a pronounced effect in reducing wrong-way entries.

The expected distribution of the 291 incidents of the second and third periods is 123 in Phase II and 168 in Phase III. The observed distribution was 158 in Phase II and 133 in Phase III. The difference between the expected and observed distributions is significant (χ^2 at 1 df = 19.82 if P < 0.001). As stated before, the preventive measures installed between these two studies were effective in reducing wrong-way entries at off ramps.

It was felt that interchanges without provisions for all possible movements might be confusing or might encourage deliberate wrong-way entry. Some insight on this possibility can be gained by comparing the combined rates of full diamond, full cloverleaf, two-quadrant cloverleaf, and buttonhook interchanges with the combined rates of the half diamond, isolated diamond ramps, and buttonhook ramps without structures (Table 15). The rate for full interchanges was approximately half the rate for partial interchanges.

The effect of providing a physical divider on the cross street was tested using the four-quadrant cloverleaf and trumpet interchanges. There was a significantly lower rate of entry when the cross street was divided, 0.83 vs 6.00 (χ^2 at 1 df = 8.32 if P < 0.01).

The rate of entry at two-quadrant cloverleaf loops (8.10) that are designed to permit both right- and left-turning movements at the cross-street terminal is not significantly different (χ^2 at 1 df = 0.01 if P > 0.90) from that for loop ramps at undivided cross streets (6.38) with only flat, merging right turns permitted. It was thought that the

BUTTONHOOKS				TRUMPETS					CUL-DE-SACS				DIRECT CONNECTS			LEFT SIDE				
W/O STRUCT.	ONE PAIR ON & OFF	ISOLATED OFF	SUB TOTAL	DIR. OFF W/O FR. RD. CONN.	DIR. OFF WITH FR. RD. CONN.	LOOP UNDIV. FROM DIR. ON	LOOP DIV. FROM DIR. ON	SUB TOTAL	NO LOCAL RD. AT BULB	WITH LOCAL RD. AT BULB	SUB TOTAL	SCISSORS	RT. SIDE	LT. SIDE	SUB TOTAL	BUTTONHOOK	DIAMOND	SUB TOTAL	SLIP RAMP	TOTAL
2	6	2	24	5	2	1	2	10	11	15	26	2	15	6	21	1	3	4	0	149
3	10	3	26	1	4	1	1	7	8	10	18	9	17	4	21	2	0	2	0	158
1	7	3	27	0	1	1	0	2	3	4	7	1	14	3	17	2	0	2	0	133
5	23	8	77	6	7	3	3	19	22	29	51	12	46	13	59	5	3	8	0	440
1	33	39	447	13	13	20	1	47	24	33	57	30	114	17	131	3	3	6	0	1753
7	48	43	544	18	15	21	1	55	27	40	67	36	147	19	166	3	3	6	0	2254
1	55	52	659	22	18	27	2	69	31	45	76	49	181	18	199	3	3	6	13	3074
08	1.07	1.05	12.92	0.39	0.34	0.53	0.03	1.34	0.64	0.92	1.56	0.90	3.46	0.42	3.88	0.07	0.07	0.14	0.11	55.66
51	24.30	6.85	7.15	51.3	20.5	6.67	266.7	28.4	61.0	60.7	60.8	8.90	17.53	47.1	21.4	44.5	133.3	89.0	NA	11.33
52	27.8	9.32	6.37	7.41	35.6	6.35	133.3	16.96	39.5	33.3	35.8	33.3	15.41	28.1	16.90	89.0	0.00	44.5	NA	9.36
36	15.3	6.92	4.91	0.00	6.67	3.48	0.00	4.45	11.61	10.90	11.05	2.45	9.28	20.0	10.25	80.0	0.00	40.0	0.00	5.24
53	21.58[c]	7.64	5.96[c]	15.38[d]	20.77[c]	5.63	100.00[c]	14.19[c]	34.38[c]	31.42[c]	32.63[c]	13.33[d]	13.28[c]	30.95[c]	15.19[c]	71.45[c]	42.90[c]	57.14[c]	0.00	7.91

[d] ENTRY RATE IS SIGNIFICANTLY DIFFERENT FROM THE AVE. (7.91) AT THE 0.05 <PROBABILITY < 0.10 LEVEL

TABLE 15

EFFECT OF FULL AND PARTIAL INTERCHANGES

Type	No. of Incidents		Exposure (per 100 ramp-years)	Rate (incidents per 100 ramp-years)[a]
	Observed	Expected		
Full interchanges (diamonds, full and two-quadrant cloverleafs, buttonhooks)	179	207	34.96	5.13
Partial interchanges (half diamond, isolated diamond ramp, and buttonhooks without structures)	75	47	7.93	9.46

[a] χ^2 at 1 df = 19.74 if $P < 0.001$.

extra left-turning ramp entrances at right angles to cross traffic might encourage wrong-way entry. Evidently, this is not the case.

It was thought that auxiliary local road connections in the middle of ramps or at ramp terminals would present more opportunities for wrong-way entry and/or complicate geometrics to cause more confusion. This apparently was not the case at the few trumpet and cul-de-sac off ramps available for comparison (28.6 incidents per 100 ramp-years with local road connections vs 27.2 at ramps without; χ^2 at 1 df = 0.01 if $P > 0.90$).

Off ramps into cul-de-sac and scissor ramps are similar in many respects. There had been evidence that both types have very high rates of wrong-way entry. This, in fact, was the case with the cul-de-sac rate, 31.6, considerably higher than the scissors, 13.4 (χ^2 at 1 df = 5.94 if $P < 0.02$).

Direct connections had approximately twice the average wrong-way entry rate (Table 14). Left-side, direct-connecting off ramps had considerably higher rates than those connecting from the right side (χ^2 at 1 df = 6.52 if $P < 0.02$), probably because the ramp is on the wrong-way motorist's right as he enters the freeway and appears to be an on ramp.

The relationships discovered by these ramp comparisons are preliminary in nature. The current movie camera survey of off ramps should uncover more definitive causative factors in the specific geometric details and traffic control devices at the ramps and crossroads. Nevertheless, the above findings, though tentative, should be considered in interchange design.

SUMMARY OF FINDINGS

A before and after comparison of incidents of wrong-way driving and of wrong-way driving accidents indicated the following:

1. The remedial measures described in the first part of the paper were very effective in reducing wrong-way driving, especially at night. The rate of wrong-way driving was reduced 60 percent on freeways and 70 percent on expressways.
2. More importantly, the measures reduced wrong-way driving accidents although to a lesser degree than wrong-way driving itself. On the basis of ramp-years, accidents were reduced 30 percent on freeways. On the basis of vehicle-miles, the rates were reduced 22 percent on freeways and 37 percent on expressways. (Because of the small number of expressway accidents, the 37 percent reduction is not statistically significant.) The freeway fatality rate was reduced 65 percent from 4.00 to 1.40 persons killed per billion vehicle-miles.
3. The measures were more effective in reducing the more severe accidents. It is estimated that in their first year of use, the remedial devices prevented approximately 65 deaths, 150 injuries, and 70 accidents.
4. A moderate additional reduction in daytime wrong-way driving (not accidents) was caused by the special GO BACK—YOU ARE GOING WRONG WAY secondary sign.
5. The special red retroreflective pavement arrow was of no benefit.

The following rates of wrong-way entry were observed by interchange types where all possible turning movements were provided:

Interchange Type	Wrong-Way Entry Rate (Incidents per 100 Ramp-Years)
Four-quad cloverleaf	2.00
Buttonhook	4.12
Two-quad cloverleaf (parclo A and B)	6.08
Diamond	7.46
Trumpet	14.19

An analysis of ramp types indicated the following:

1. All turning movements should be provided at interchanges; otherwise, wrong-way entry at the remaining ramps increases.
2. Off ramps that force merging at flat angles at the cross street (cloverleaf right-turn ramps, loop ramps) have the lowest entry rates.
3. A physical divider on the cross street helps prevent wrong-way entry to the off ramps.
4. Left-side off ramps should be avoided. To the wrong-way driver, they appear much like a right-side on ramp at the freeway, adding confirmation that he is going the "right way."

A correlation was found between sight distance and frequency of wrong-way driving accidents, with 60 percent of these accidents occurring where sight distance was restricted to 1,200 ft or less. (Sight distance is measured to a 2.0-ft headlight height because most of these accidents occurred at night.)

The typical wrong-way driver is not handicapped physically or mentally to any greater degree than the average driver. His mental attitudes and outlook, however, may be considerably different as reflected by the fact that he receives considerably more driving violation convictions and felony convictions than the average driver. He also is involved in considerably more accidents.

The at-fault wrong-way driver in wrong-way accidents has an equal disregard for the driving laws and a greater disregard for criminal laws than wrong-way drivers in general. Those human characteristics that make him disregard the rules established by society may also be causing him to have more accidents regardless of the reason he was driving the wrong way in the first place.

The wrong-way driving accident problem is caused primarily by the male driver. Less than 10 percent of these accidents are caused by women even though they are doing approximately 20 percent of the wrong-way driving and constitute approximately 40 percent of the licensed drivers.

CONCLUSIONS AND RECOMMENDATIONS

Wrong-way driving on freeways and expressways can be reduced a substantial amount, perhaps two-thirds, using (a) white-on-red WRONG WAY signs with black-on-white DO NOT ENTER signs at off ramps and ends of freeways and expressways, (b) white-on-green FREEWAY ENTRANCE signs at on ramps, and (c) large white pavement arrows at all off ramps, on ramps, expressway at-grade crossings, median openings, and ends of freeways and expressways.

More importantly, wrong-way driving accidents can be reduced by one-third and fatalities by two-thirds on freeways and one-fifth on expressways with these devices.

Further reductions can be achieved by proper choice of off-ramp types and by paying attention to certain specific geometric details such as (a) making the junction of off ramps to cross streets as flat as possible to be obvious that entry is not intended and to make such entries difficult, (b) dividing the cross street, (c) eliminating left-side off ramps, (d) providing for all possible turning movements, and (e) providing a minimum of 1,200 ft of sight distance (3.75-ft right-way driver eye height to 2.0-ft headlight height).

More research is needed and some is under way concerning more definitive correlations between specific geometric details and traffic control measures and the rate of wrong-way entry at off-ramp terminals. There is also a need to develop and test control devices for wrong-way movements that do not originate at freeway off ramps, expressway at-grade crossings, and freeway termini, and as a secondary line of defense for drivers who fail to see or react to the control devices at the off ramps.

ACKNOWLEDGMENTS

The successful conduct of this project is due, to a great extent, to the excellent cooperation and support of many individuals and agencies. The cooperation of the California Highway Patrol and the City Police Departments of Los Angeles, Long Beach, Riverside, and San Diego in furnishing special wrong-way driving incident reports is hereby gratefully acknowledged.

David J. Theobald, California Division of Highways, was research project engineer during most of this study. He was largely responsible for the analysis on the effect of sight distance, for collecting most of the data presented herein, and for making the preliminary analyses. Thomas G. Hansen, California Department of Motor Vehicles, supervised the driver interviews.

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Appendix

CHI-SQUARE METHOD

The chi-square test (11) was used to test whether the differences in accidents and incidents were statistically significant. Generally, a confidence level of 0.05 was used. (A significant difference could have occurred by chance only 5 times out of 100.) The chi-square test compares observed and expected frequencies. The expected frequencies are computed under the hypothesis that the sum of accidents (or incidents) of both periods should distribute in proportion to the exposure in each period.

In the report, statistical reliability of observed changes is often indicated parenthetically, e.g., χ^2 at 1 df = 3.90 if $P < 0.05$. This means that the computed chi-square value was 3.90. At one degree of freedom, this value (3.90) would be expected to occur by chance less than 5 times out of 100. Thus, we can be 95 percent confident that the difference observed was a true difference and not caused by random sampling fluctuations.

Discussion

JAMES E. WILSON, Deputy Director, Highway Safety Programs Service, National Highway Safety Bureau—Seldom does a discussant have the opportunity to be in the position that I am in today. This will take some explanation, and I will endeavor to do just that.

While still working with the California Division of Highways, I was intimately connected with portions of the various study phases involved in Tamburri's paper. This problem of wrong-way drivers was one of unknown quantity in the early 1960's. Until a couple of serious wrong-way crashes occurred, and an initial report by Charlie Gay (1), no one really knew the magnitude of the problem. It was a special problem that was not encountered on conventional highways, but was limited to highways having partial or total control of access with opposing lanes separated by varying widths. Although the total crash problem of the wrong-way driver is a far more complex issue than is spelled out in Tamburri's paper, he did zero in on a very important segment of the problem with which the National Safety Bureau, through its multiphased programs, is trying to cope. Effort is contemplated on the behavior of the driver himself, but before we can make any headway in this field, we must know the characteristics of the drivers that are giving us the trouble.

Tamburri's paper certainly fulfills one very important void to which no one has as yet addressed himself. It is the product of cooperation among city police officials, state patrol officers, highway department personnel, motor vehicle people, and others. The study even reached into areas never before considered by highway people. In seeking information from the Bureau of Criminal Identification and Investigation of the Justic Department of the State of California, new avenues have been explored. With this kind of cooperation, crashes can be reduced.

It may be said that a better explanation might have been made in defining the various phases of this study, and that the sample was too small to be indicative of anything worthwhile, but let me be quick to point out that the periods of time in the various phases were equal. Should the question be asked, "Were the number of incidents influenced by the fact that the study phases were in different parts of the year?"

The sample could not have been expanded easily because these incidents and accidents are really rare occurrences, even though they cause great consternation for engineering and enforcement officials when such crashes do occur. They are always associated with what may be clearly defined as an at-fault driver and an innocent driver as opposed to the "pure accident" experienced if two vehicles reached an uncontrolled intersection at precisely the same moment. If I would have any criticism to make of the research findings, and I would be quick to point out that I am not a researcher, it would be that variation may exist in reporting of incidents. This could vary from area to area and city to city. It can also be dependent on the density of patrol effort, and the diligence that any patrol officer may lend to any special report required during his otherwise hectic day. Was patrol effort in the various phases uniformly applied?

Perhaps I could comment by raising some other questions that come to mind. For instance, why did the number of reported incidents decrease on the freeway lanes and increase in the ramp areas? Why was there a reduction in incidents in all but the hours of from 2:00 to 4:00 a.m.? (For those of you unfamiliar with California, the bars close at 2:00 a.m.) If I were to comment on this question, I would say that remedial measures connected with alcohol and highway safety might also be able to effect a reduction between these hours. It could also mean that while the drinking driver is behind the wheel of his car, those remedial measures taken between Phase I and Phase II, as well as between Phase II and Phase III, are not effective. I can comment with some authorit that if physical obstructions were placed to really reduce the incidents of wrong-way driving between these hours, then more innocent victims may become accident victims. This would be due to the presence of broken-down vehicles in places where right-way traffic would least expect them. Another comment is concerned with the 224 drivers interviewed: all were alive, naturally, do these 224 drivers coordinate well with those who might have been interviewed but who lost their lives in crashes of this type.

A fact unknown to me, but perhaps known to many, was that 10 percent of the people interviewed had no legal driving authority. They had lost their licenses, they had had their licenses revoked, they had never been licensed drivers, and one individual had been driving since 1951 without a driver's license. I have heard it said that people without legal authority to drive may be more careful, but the facts here do not support that theory.

In the section regarding wrong-way drivers involved in accidents, one of my staff members, after reviewing the paper, raised the question of how the "at-fault driver" was defined. This raised an interesting question, but I assured him that the "at-fault driver" was always the driver who was going down the freeway in the wrong direction. This seemed like a logical explanation, but I wonder if maybe the fault could not be attributed to someone other than the driver, and that perhaps both drivers in some instances are innocent victims of some other unplanned event or circumstance.

Let me cite a few examples. Perhaps some other incident occurring at an entrance ramp removed whatever evidence there was that entry was denied, and before it could be repaired or replaced by proper maintenance, someone drove into it in the wrong direction. Perhaps, inadvertently, guide signs were placed at locations that actually misdirected the at-fault driver. Perhaps the design was of such configuration that it was easier to make a choice to go in the wrong direction than in the right direction. Whose fault is this? Perhaps snow or ice covered other pertinent markings that would have controlled the wrong-way or at-fault driver.

Perhaps I had a preconceived notion that I cannot attribute to any particular thing at this time that some wrong-way accidents were deliberate attempts at suicide. I do believe that there were a couple of cases where this could have been proven, and, in fact, in one case of which I am aware there was even a confession to this effect. However, I know that the statistics between those drivers interviewed who merely had a wrong-way incident charged against them were the same or almost the same as those where wrong-way accidents actually occurred. If I have interpreted this correctly, this throv my suicide theory into a cocked hat.

All in all, I believe this paper confirmed some thinking of mine in years past that the highway safety problem is a social problem of tremendous magnitude that deals witl a great many aspects of our society, aspects not necessarily connected with the automobile. The people described in this paper are, in my opinion, not just gamblers or victims of a poor highway environment, they are just plain bad actors with social problems off the highway, too—problems with the police, problems in their own homes, and problems wherever they go. In spite of the "fact" one hears that people involved in accidents are just plain people close to home, one might find out otherwise if one made an in-depth investigation in other small areas of the total crash problem.

In closing, let me cite an example of one of the people I previously mentioned—the gambler. During one of the study phases, it was found that a school bus driver with children entered a ramp in the wrong direction, drove down the highway for about half a mile, and exited in the wrong direction for a considerable period of time before he was caught. Now let me ask you, what kind of man is this who would expose your children or anyone's children to this sort of hazard just to save a half mile of additional driving?

ALGER F. MALO, Director of Department of Streets and Traffic, Detroit—This study, describing the characteristics of drivers involved in wrong-way incidents and accidents, is a subject of considerable importance. The answer to this problem is being sought by highway and traffic engineers responsible for the design of expressways and freeways. The study not only collects biographical and environmental information concerning the wrong-way driver, but also reveals the time and circumstances under which the violation occurs. It is not surprising to note that weekends and the hours of darkness, especially between 2:00 a.m. and 4:00 a.m., account for a large percentage of the wrong-way driving when the figures also reveal that over half the drivers "had been drinking." The preventive measures evidently were effective in reducing incidents between 10:00 p.m. and 2:00 a.m., but in my opinion the number still seems higher than might be expected, especially in the daytime hours.

It appears significant that wrong-way drivers have an accident rate twice that of the average California driver, and that they commit approximately twice as many violations as the average drivers, and that drivers involved in wrong-way accidents had accident and violation records approximately the same as a group involved in only wrong-way incidents, but had a considerably higher criminal record. They were all experienced drivers, however, averaging 25 years of driving and 15,000 miles per year. Few had any visual difficulty or any more physical or mental handicaps than the average driver.

It could be concluded that the driver so involved has no regard for law and order, and that this characteristic explains his behavior in wrong-way driving. I believe it is more likely that these individuals lack understanding of the geometrics of the highway, do not read signs or, if so, do not understand their meaning, and are generally careless drivers. I believe it is more significant that the biggest single group involved in this violation is the "blue-collar" worker, and that there are a small number of professional drivers involved. Another important factor was the large increase noted in the percentage of wrong-way incidents occurring on the newer facilities with light traffic. This unquestionably indicates that some drivers become involved because of their unfamiliarity with the facility, and the light traffic does not provide directional information such as that experienced on a heavily traveled highway. It does not seem logical that anyone, no matter what kind of driving record he may have or what his criminal tendencies might be, would drive the wrong way purposely on a high-speed freeway.

I believe this study adequately reveals the character of the wrong-way drivers and satisfactorily fulfills the objective of the project. It appears, however, that if the traffic engineer is to approach the solution to this problem, he must know more than who the driver is and when he commits the violation. Research to determine why the driver mistakes an exit for an entrance is of greater importance if methods are to be devised for minimizing this dangerous practice. Unfortunately, it may take drastic measures if a large percentage of the drivers as shown in this study "had been drinking."

THOMAS N. TAMBURRI, Closure—Both Malo and Wilson have brought up some very interesting and pertinent points in their discussions. Mr. Malo commented that, "It does not seem logical that anyone, no matter what kind of driving record he may have or what his criminal tendencies might be, would drive the wrong way purposely on a high-speed freeway." In the original study (1), approximately one-fifth of the wrong-way motorists intentionally drove the wrong-way. In most cases, it was for a short distance to eliminate circuitous travel. Probably an additional large percentage were also deliberately driving the wrong-way but had sufficient presence of mind not to admit it to the officer. Some wrong-way driving was repetitive, such as that of the school bus driver mentioned by Mr. Wilson.

The author concurs with Mr. Malo that more research, perhaps by human factors consultants, is needed to determine why the driver makes his mistake. It is hoped that the camera survey currently under way will provide some insight in this area.

Mr. Wilson raised the question of whether the frequency of incidents observed was biased because each study phase did not include the identical 9 calendar months. If there are any seasonal fluctuations in wrong-way driving, then, of course, the study would be biased. Even so, the bias in comparing any two study periods would be limited because only three months would be different. Mr. Wilson also commented that the incidents study may have been biased by differences in reporting levels between cities, geographic areas, and individual enforcement officers. This type of variation should be random. Geographically, it should be minimal because substantially the same areas and cities were involved in each study.

Although the number of incidents increased in the ramp areas but decreased on the freeway lanes ("Other U-turns on off or on ramps" of the second portion of Table 6), the change from 10 to 14 is not statistically significant, especially considering the increased exposure in Phase III.

Only 168 wrong-way motorists were interviewed. The remaining 56 had left the state, failed to appear, or were deceased (8). For the eight deceased drivers, there was a great deal of data available from their driving records, accident records, and from records of the Bureau of Criminal Statistics and the California Department of Public Health. However, because of the small sample size, it was felt that any comparison of these eight drivers with the remaining 216 would be meaningless.

An Evaluation of the Effectiveness of Televised, Locally Oriented Driver Reeducation

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Television, with its ability to reach large audiences, has been used extensively in driver-education efforts but its effectiveness has never been measured. The purpose of this research was to measure the effectiveness of a televised, locally oriented, "candid camera" type of driver reeducation program. The measures of effectiveness included a study of changes in driver errors at 8 local intersections and an analysis of changes in accident-involvement rate for 48 local intersections.

The televised program entitled "Traffic Madness" consisted of an 18-month series of 2- to 3-minute locally oriented traffic safety films, produced by research project staff. These showed local drivers in the process of making errors at both rural and urban locations throughout Lexington-Fayette County, Kentucky. In sequence with each type of driver error shown, the corresponding correct driving procedure was illustrated.

Both driver errors and total accidents were significantly reduced 17.4 percent ($p < 0.01$) and 12.5 percent ($p < 0.01$) respectively. Driver errors were counted only during home-from-work rush hour traffic on Tuesdays and Thursdays from 4:00 to 5:30 p.m., whereas the accident study encompassed all hours of the week when out-of-county drivers not exposed to the program made up a proportionately larger percentage of drivers in the sample.

•THE EFFECTIVENESS of many currently vogue driver-education efforts is the subject of much doubt. High school and commercial driver-education efforts have been shown to be self-selective processes, reaching a limited number of drivers. Most of these drivers are among the most youthful in the driving population who account for less than one-third of all accidents. Study results vary widely. The effects, whenever measured, have been shown to wear off after a period of 1 to 5 years (1).

Judicial safety training programs, although certainly reaching drivers who need help, have not been evaluated fully. Here again, study results vary and the initial effects diminish after a 12-month period.

Mass-media efforts have been somewhat random in nature, and their effectiveness has usually not been measured. Television, with its ability to reach large audiences, has been used most extensively, but its effectiveness has never been measured (2).

PURPOSE AND SCOPE OF STUDY

The purpose of this research was to measure the effectiveness of a televised, locally oriented, "candid camera" type of driver reeducation program. The measures of effectiveness included a study of changes in driver errors at 8 local intersections and an analysis of changes in accident-involvement rates at 48 local intersections.

Paper sponsored by Committee on Road User Characteristics.

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Air time for the program was donated by local commercial television stations as a public service. Because of the candid camera nature of the films, it was not possible to seek commercial advertising sponsorship of the program; films were shown strictly in the public interest in order to avoid invasion of privacy claims.

Airing of the program began in late October 1966 and was interrupted from August 1967 through February 1968, during which time a study of the longevity of noted early effects was conducted. Continuous airing since February 1968, beyond the planned May 1968 demise of the program, has been prompted by encouraging results from the driver-error and accident studies. Means of continuing the local program indefinitely and expanding the locally oriented candid camera technique to statewide coverage have been under study by the Kentucky Department of Public Safety since January 1968.

"Before-during-and-after" counts of driver errors were made at 8 local intersections representative of the range of intersection types and traffic movements encountered in the Lexington area. Eleven types of driver errors were separately recorded. These errors included lane hopping, running red light, running yellow light, discharging or loading passengers in traffic, violating turn signal, conversing with occupants of another vehicle, turning from improper lane, making through movement from turn lane, operating vehicle in poor mechanical condition, turning into improper lane, and stopping over stop line. These data were analyzed to determine the amount, significance, and longevity of changes in driver habits resulting from the televised driver reeducation program.

The 48 local intersections with the greatest number of accidents in 1965 were selected for the study of changes in accident involvement rate. Accident data for these intersections were analyzed for a 5-year "before" period, November 1961 through October 1966, and for a $1\frac{1}{2}$-year "after" period, November 1966 through April 1968.

PROCEDURE

A 16-mm, Cine-Kodak K-100, three-lens turret camera was used in filming most of the traffic situations at intersections. Another 16-mm camera, L-W Photo Cine Pulse MK-100 ES, was used on a combination through-the-roof automobile mount and aiming device to film traffic operations and driver errors from the traffic stream. The remote intervalometer timing unit, used to control the operation of the camera from inside the vehicle, provides for frame frequencies ranging from 5 frames per second to 1 frame per minute with a constant $\frac{1}{50}$-second exposure.

All films were taken at 24 frames per second with the exception of those used at the opening and closing of each TV show. The Cine Pulse feature of the MK-100 ES camera was used to produce opening and closing "fast" film, using a speed from 1 frame per second to 8 frames per second depending on the speed of traffic operations being filmed. This film, when shown at 24 frames per second, made traffic appear to be traveling at speeds up to 60 mph through an intersection. When accompanied by music with a fast beat, it made a good attention getter, especially because it usually erupted in the middle of news-weather-sports broadcasts and showed an intersection familiar to the viewer. The basic idea in each of the films was to illustrate a driver error and show the corresponding correct driving procedure.

Several approaches were used to obtain these films. The first films were made from street level with a stationary camera. In most cases, a number of examples of correct and incorrect movements had to be filmed in order to obtain clear, easily understood examples. This required from 1 to 2 hours of filming time and approximately 200 ft of film for each 2- to 3-minute show.

Filming from the street level proved unsatisfactory for showing some types of of driver errors. It was often necessary to include films taken from locations above the street such as apartment building balconies, upper story windows of downtown buildings,

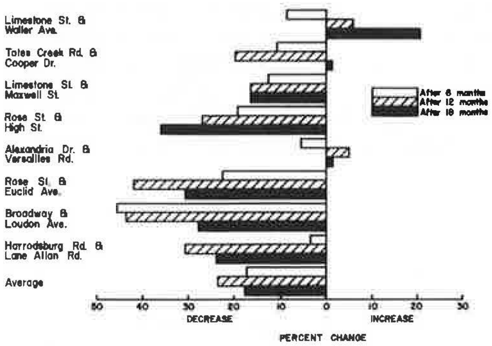

Figure 1. Effect on number of driver errors per 1,000 vehicles at each intersection.

and the upper floors of parking garages. Traffic operations filmed from above the street were clear and easily explainable; lane striping and painted arrows were more visible.

Because many driver errors could not be filmed from stationary camera locations, an automobile-mounted camera was used to film traffic situations from the traffic stream. This approach allowed TV viewers to observe driving errors and corrections from the same angle that they are seen in practice.

The format for each movie was in keeping with the title "Traffic Madness." The title and credits were given in the first and last 20 seconds of the show, backed by the "fast" motion film. After the opening credits, the driving errors and traffic movements were shown at normal speed. Each movie began with a general view of the intersection, ramp, or section of roadway, followed by a view of the street name sign including any readily recognizable landmarks that would help to familiarize viewers with the location. This positive orientation served to force the viewer to closely associate his own habits and driving philosophy with the driving tasks under discussion by the narrator. The narrative was kept light and humorous because most drivers resent lectures on their driving habits.

Arrangements were made during late summer and early fall of 1966 with WKYT-TV, Channel 27 in Lexington, to air the shows each Tuesday and Thursday at 9:30 a.m. and 6:25 p.m. in lieu of the station's daily public service announcement and editorials. Morning shows were aimed at exposure to housewives and nonprofessional viewers. The afternoon shows were aired during prime television time, along with the news, weather, and sports, and consequently held the largest viewing audience.

During the summer of 1967, ownership and management of WKYT-TV changed. Subsequently, the show was dropped from the programming schedule of WKYT-TV. Efforts to reschedule the program were unsuccessful. Six months elapsed before the program

TABLE 1

DRIVER ERRORS PER 1,000 VEHICLES

Intersection	Before	After	Difference (percent)	Statistically Significant	Intersection Operational Change Made
Limestone St. and Waller Ave.	178.81	215.41	+20.48	yes ($p = 0.01$)	yes
Tates Creek Rd. and Cooper Dr.	167.25	169.59	+ 1.39	no ($p = 0.86$)	no
Limestone St. and Maxwell St.	309.39	259.44	-16.15	yes ($p < 0.01$)	no
Rose St. and High St.	317.13	203.10	-35.94	yes ($p < 0.01$)	no
Alexandria Dr. and Versailles Rd.	369.81	375.18	+ 1.45	no ($p = 0.78$)	yes
Rose St. and Euclid Ave.	394.56	274.78	-30.38	yes ($p < 0.01$)	no
Broadway and Loudon Ave.	376.48	272.59	-27.60	yes ($p < 0.01$)	yes
Harrodsburg Rd. and Lane Allen Rd.	369.54	281.32	-23.87	yes ($p < 0.01$)	no
Average	310.37	256.42	-17.38	yes ($p < 0.01$)	–

was reestablished on WLEX-TV, Channel 18. Part of this time was consumed in the changeover from black and white to color movies (Channel 18 is an all-color station).

The show is now aired only once per week at 5:30 p.m. each Thursday, still during prime television time, immediately preceding the weather, news, and sports. Although the 6-month lapse in airing of the television show was not planned, it did provide the opportunity for an important test of the longevity of the noted effects from the first 12 months of the program.

RESULTS

After the first 6 months of the program, the average of all 11 driver errors for all 8 intersections showed a statistically significant decrease of 17 percent. Twelve months after the beginning of the program there was an additional 6 percent decrease even though films were not aired during the latter 2 months of this period. After 18 months, the reduction reverted back to the original total of 17 percent (Table 1), probably because of the fact that films were aired only once per week during the last 2 months and not at all during the immediately preceding 6 months. These fluctuations are illustrated in Figure 1. Some seasonal effects may be reflected in these fluctuations. Nevertheless, they indicate that beneficial effects from this type of effort will dwindle with time unless the brief television shows are kept on the air and shown more than once per week. Part of the reason for this otherwise expected regression is the influence of out-of-county and out-of-state drivers who cannot be reached by the program.

Drivers follow each other like sheep; errors very frequently are committed by platoons of drivers. Without the continuous influence of the televised program, local drivers will revert to follow-the-out-of-town-leader driving habits. This is reflected in the difference between driver-error reductions and accident-involvement rate reductions.

The reductions in both total accidents and accident-involvement rate were smaller than the observed driver-error reduction (Table 2). This derives partially from the fact that driver errors were counted only on Tuesdays and Thursdays, 4:00 to 5:30 p.m., when local home-from-work trips comprised a major portion of the traffic stream, whereas accident data encompassed all hours of the week when out-of-county drivers make up a proportionately larger share of all drivers.

The data in Table 3 illustrate the lack of effect of the program on out-of-county drivers. Not only is there a great difference between driver-error reductions for in-county and out-of-county drivers (21.32 vs 1.87 percent), but the only significant increase in driver errors at any of the 8 sample intersections was for out-of-county drivers.

The large increase in out-of-county driver errors at the Limestone Street-Waller Avenue intersection (Table 3) is solely responsible for the only overall statistically significant increase in driver errors (Tables 1 and 4). Out-of-county drivers were responsible for two-thirds of the increase in errors at this intersection (Table 1). This large increase was caused by a poorly redesigned approach on one leg of the intersection. Shortly after the beginning of this study, a one-lane Waller Avenue approach was made into a two-lane approach with insufficient widening of the roadway to accommodate the additional lane, insufficient curb radius to accommodate right turns, and insufficient length of widening to provide minimum acceptable storage capacity for the left-turn volume.

A large increase in out-of-county driver errors was also caused by redesign of the Alexandria Drive-Versailles Road intersection during this study (Table 3). However, the changes adequately provided for all traffic movements, except one, and there was a small, statistically insignificant decrease in errors committed by in-county drivers.

The extent to which the effects of design changes at these two intersections overshadowed the effects of the driver reeducation program is shown in Figure 1. An operational change was also made at the intersection of Broadway and Loudon Avenue during the study, but appears to have had little or no overall effect on driver errors. Driver-error data were analyzed separately for the group of 5 intersections at which no operational changes were made during the study. The results, shown in Figures 2 and 3, are more striking in some respects than the average results from all 8 study intersections

TABLE 2

MEASURES OF EFFECTIVENESS

Measure	Before (Nov. 1965 to April 1966)	After (Nov. 1967 to April 1968)	Difference (percent)	Statistical Significance
Total accidents	489	428[a]	-12.5	yes ($p < 0.01$) (Poisson)
Accidents per 10^6 vehicles	115	100	-13.0	no ($p = 0.09$) (Poisson)
	Before (Oct. and Nov. 1966)	After (April 1968)		
Driver errors per 1,000 vehicles	310	256	-17.4	yes ($p < 0.01$) (chi-square)

[a]Adjusted for volume changes (3).

TABLE 3

COMPARISON OF CHANGES IN NUMBER OF ERRORS COMMITTED BY IN-COUNTY AND OUT-OF-COUNTY DRIVERS

Intersection	Driver Errors per 1,000 Vehicles							
	In-County				Out-of-County			
	Before	After	Difference (percent)	Statistically Significant	Statistically Significant	Difference (percent)	After	Before
Limestone St. and Waller Ave.	134.55	146.73	+ 9.06	no ($p = 0.29$)	yes ($p < 0.01$)	+55.20	68.68	44.25
Tates Creek Rd. and Cooper Dr.	135.19	138.59	+ 2.52	no ($p = 0.77$)	no ($p = 0.85$)	- 3.40	31.00	32.06
Limestone St. and Maxwell St.	251.45	213.88	-14.95	yes ($p = 0.02$)	no ($p = 0.10$)	-21.35	45.57	57.94
Rose St. and High St.	243.06	140.28	-42.27	yes ($p < 0.01$)	no ($p = 0.19$)	-15.20	62.81	74.07
Alexandria Dr. and Versailles Rd.	297.83	287.13	- 3.60	no ($p = 0.53$)	no ($p = 0.06$)	+22.32	88.00	71.97
Rose St. and Euclid Ave.	285.10	174.44	-38.83	yes ($p < 0.01$)	no ($p = 0.38$)	- 8.38	100.34	109.46
Broadway and Loudon Ave.	333.79	235.95	-29.31	yes ($p < 0.01$)	no ($p = 0.35$)	-14.22	36.63	42.70
Harrodsburg Rd. and Lane Allen Rd.	299.68	221.40	-26.12	yes ($p < 0.01$)	no ($p = 0.23$)	-14.23	59.93	69.86
Average	247.58	194.81	-21.32	yes ($p < 0.01$)	no ($p = 0.67$)	- 1.87	61.62	62.79

TABLE 4

NUMBER OF DRIVERS MAKING AT LEAST ONE ERROR PER 1,000 VEHICLES

Intersection	Before	After	Difference (percent)	Statistically Significant
Limestone St. and Waller Ave.	151.62	188.49	+24.32	yes ($p < 0.01$)
Tates Creek Rd. and Cooper Dr.	156.04	156.52	+ 0.31	no ($p = 0.97$)
Limestone St. and Maxwell St.	256.08	192.12	-24.98	yes ($p < 0.01$)
Rose St. and High St.	249.23	182.58	-26.74	yes ($p < 0.01$)
Alexandria Dr. and Versailles Rd.	306.61	315.05	+ 2.75	no ($p = 0.63$)
Rose St. and Euclid Ave.	330.86	229.34	-30.68	yes ($p < 0.01$)
Broadway and Loudon Ave.	290.07	219.50	-24.33	yes ($p < 0.01$)
Harrodsburg Rd. and Lane Allen Rd.	318.93	243.84	-23.54	yes ($p < 0.01$)
Average	257.43	215.93	-16.12	yes ($p < 0.01$)

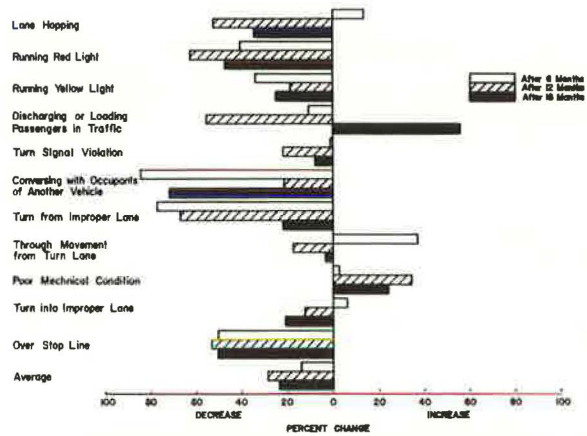

Figure 2. Effect on number of driver errors per 1,000 vehicles, average of five intersections.

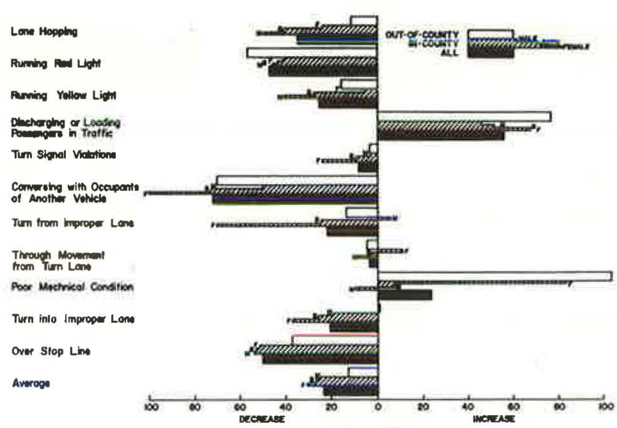

Figure 3. Effect on number of driver errors per 1,000 vehicles after 18 months, average of five intersections.

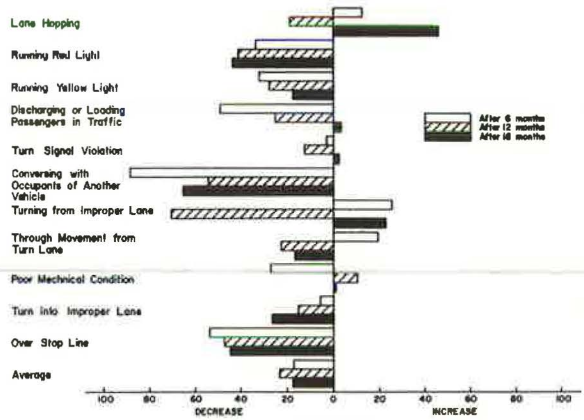

Figure 4. Effect on number of driver errors per 1,000 vehicles, average of eight intersections.

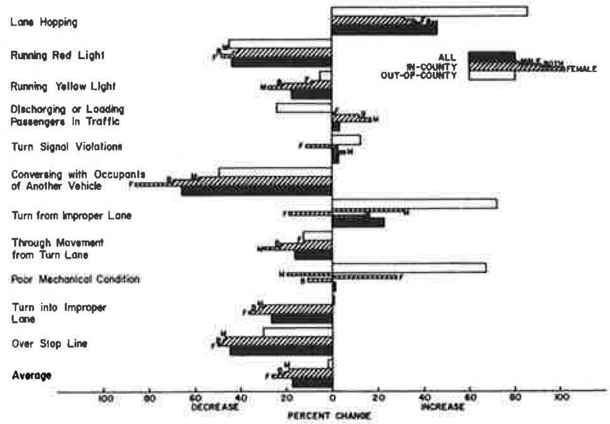

Figure 5. Effect on number of driver errors per 1,000 vehicles after 18 months, average of eight intersections.

(Figs. 4 and 5). However, overall conclusions from both analyses are the same. Except as specifically noted, the discussion and tables herein are based on the more conservative results from all 8 intersections.

The data in Tables 5, 6, and 7 show some of the types of effects the program had on driver errors. As indicated by the lack of any statistically significant difference in number of driver errors per erratic vehicle (Table 5), the decrease in driver errors resulted from a decrease in the number of drivers committing errors and not because of a decrease in the number of errors committed per driver.

Because of the midmorning broadcasts of the program, televised films probably had greater exposure to female drivers than male drivers. This may be partially responsible for the difference between the male and female driver-error reductions in Table 6. Female driver errors were reduced by 21.23 percent, whereas male driver errors were reduced only 15.51 percent. Female drivers accounted for 41 percent of the driver-error reductions even though they comprised only 33 percent of the errant drivers in the "before" period. This difference of effects on female and male drivers appears slightly greater when in-county and out-of-county drivers are analyzed separately; the female and male in-county driver-error reductions are 26.39 and 18.73 percent respectively, whereas the changes in driver errors for out-of-county females and

TABLE 5

NUMBER OF DRIVER ERRORS PER ERRATIC VEHICLE

Intersection	Before	After	Difference (percent)	Statistically Significant
Limestone St. and Waller Ave.	1.18	1.14	- 3.39	no (p = 0.97)
Tates Creek Rd. and Cooper Dr.	1.07	1.08	+ 0.93	no (p = 0.99)
Limestone St. and Maxwell St.	1.21	1.35	+11.57	no (p = 0.90)
Rose St. and High St.	1.27	1.11	-12.60	no (p = 0.89)
Alexandria Dr. and Versailles Rd.	1.21	1.19	- 1.65	no (p = 0.98)
Rose St. and Euclid Ave.	1.19	1.20	+ 0.84	no (p = 0.99)
Broadway and Loudon Ave.	1.30	1.24	- 4.62	no (p = 0.96)
Harrodsburg Rd. and Lane Allen Rd.	1.16	1.15	- 0.86	no (p = 0.99)
Average	1.20	1.18	1.67	no (p = 0.97)

TABLE 6

COMPARISON OF CHANGES IN NUMBER OF ERRORS COMMITTED BY MALE AND FEMALE DRIVERS

Intersection	Female				Male			
	Before	After	Difference (percent)	Statistically Significant	Statistically Significant	Difference (percent)	After	Before
Limestone St. and Waller Ave.	60.92	66.54	+ 9.19	no (p = 0.47)	yes (p < 0.01)	+26.31	148.88	117.88
Tates Creek Rd. and Cooper Dr.	65.66	66.12	- 0.67	no (p = 0.96)	no (p = 0.85)	+ 1.85	103.47	101.58
Limestone St. and Maxwell St.	96.56	56.24	-47.76	yes (p < 0.01)	no (p = 0.51)	- 4.53	203.20	212.82
Rose St. and High St.	93.36	58.63	-37.16	yes (p < 0.01)	yes (p < 0.01)	-35.43	144.47	223.77
Alexandria Dr. and Versailles Rd.	128.15	119.10	- 7.05	no (p = 0.42)	no (p = 0.35)	+ 5.95	256.09	241.66
Rose St. and Euclid Ave.	129.25	86.31	-33.27	yes (p < 0.01)	yes (p < 0.01)	-28.98	188.47	265.31
Broadway and Loudon Ave.	105.05	72.03	-31.45	yes (p < 0.01)	yes (p < 0.01)	-26.11	200.56	271.43
Harrodsburg Rd. and Lane Allen Rd.	134.53	115.93	-13.83	no (p < 0.01)	yes (p < 0.01)	-29.62	165.40	235.00
Average	101.68	80.11	-21.23	yes (p < 0.01)	yes (p < 0.01)	-15.51	176.32	208.68

males were +2.70 and -3.71 percent respectively. Although none of these differences in effect on male and female drivers is statistically significant, they do appear to reflect the greater exposure of televised driver reeducation program to in-county females.

Not all of the 11 types of driver errors were reduced and, for those that were reduced, the amounts of change varied widely (Table 7). Among the many reasons for these variations, the following are probably the most significant:

1. The quality and quantity of televised film coverage of the different types of errors varied widely.
2. Traffic capacity was so inadequate as to encourage certain types of driver errors at 7 of the 8 intersections.

TABLE 7

CHANGE IN THE NUMBER OF ERRORS OF EACH TYPE COMMITTED PER 1,000 VEHICLES

Type of Error	Before	After	Difference (percent)	Statistically Significant
Lane hopping	69.34	101.12	+45.82	yes (p < 0.01)
Running red light	141.54	79.74	-43.68	yes (p < 0.01)
Running yellow light	256.43	211.42	-17.55	yes (p < 0.01)
Discharging or loading passengers in traffic	18.65	19.29	+ 3.27	no (p = 0.89)
Violating turn signal	815.25	837.04	+ 2.66	no (p = 0.45)
Conversing with occupants of another vehicle	19.30	6.64	-65.54	yes (p < 0.01)
Turning from improper lane	7.04	8.66	+22.80	no (p = 0.54)
Making through movement from turn lane	63.12	52.90	-16.18	no (p = 0.20)
Operating vehicle in poor mechanical condition	31.78	32.17	+ 1.10	no (p = 0.95)
Turning into improper lane	628.14	463.63	-26.19	yes (p < 0.01)
Stopping over stop line	432.33	238.80	-44.77	yes (p < 0.01)
Average	310.37	256.42	-17.38	yes (p < 0.01)

3. Because of the lack of adequate maintenance funds, the condition of painted pavement markings varied during the study.
4. Overhead lane control signs are, in the case of most of the 8 sample intersections, either inadequate or nonexistent.
5. Design and operational changes at 3 of the 8 intersections caused increases in some types of errors during the period of driver adjustment.
6. Table 7 includes both in-county and out-of-county drivers; when only in-county drivers are considered, some of the error increases are smaller and many of the error decreases are more substantial.

The multiplicity of factors effecting any given driver error can be illustrated in connection with lane hopping and turn signal violations.

Lane Hopping

Lane hopping is the only driver error for which a statistically significant increase was noted. The percent change was +45.83 percent, which has a significance of $p < 0.01$.

Four of the 8 intersections show increases in lane hopping. These are Tates Creek Road-Cooper Drive, Alexandria Drive-Versailles Road, Broadway-Loudon Avenue, and Rose Street-Euclid Avenue. The amount of increase in lane hopping is statistically significant only in the first two cases.

At these 4 intersections it was observed that drivers wishing to make left turns must do so against a high volume of oncoming traffic. The delay caused by the oncoming traffic soon results in long queues of drivers apparently awaiting a left-turn opportunity. However, observations seem to indicate that drivers are within the queues for a variety of reasons: some intend to turn left, some could not change lanes because of traffic in adjacent lanes, and some happened into the turn lane by mistake, because of either poor marking or recent changes in lane use regulations. When the delay becomes undesirable, some drivers change lanes illegally. During rush hour, delays become quite lengthy (in some instances, a maximum of two vehicles can turn during each cycle) and an increase in lane hopping occurs.

The device used for control of this error is a solid, white stripe extending between lanes 50 to 100 ft from the intersection. Immediately after the final driver-error counts in 1968, all 8 intersections were restriped, indicating the poor condition of striping at the time of the counts. The poor quality of the markings resulted in some of the error increases. Striping and other intersection markings were, in general, in good condition at the time of the "before" count.

The increase in number of out-of-county drivers committing this driver error was twice the increase in number of in-county drivers committing the same error, 84.72 and 35.81 percent respectively. This difference can largely be attributed to the fact that local drivers are more familiar with the intersections.

Lane hopping received little attention in the televised films. This error was difficult to film because the only acceptable camera vantage point was from within the traffic stream, and traffic moved slowly. The required technique was so time-consuming and inefficient that lane hopping was presented only at random along with other errors and never singled out for special attention.

Turn Signal Violations

Turn signal violations increased at 5 of the 8 intersections. Table 7 shows a statistically insignificant increase of 2.66 percent ($p = 0.45$). Two of the intersections where increases occurred are those where design changes were made.

In-county drivers show an increase of 0.27 percent ($p = 0.94$) whereas out-of-county drivers committing this error increased by 12.20 percent ($p = 0.12$). Male drivers committing the error increased 5.81 percent ($p = 0.16$) whereas a decrease of 4.60 percent ($p = 0.47$) was found for female drivers. Closer examination of the decrease for female drivers reveals that in-county female driver errors of this type decreased by 11.42 percent ($p = 0.10$) while for out-of-county female drivers there was a 27.96 percent ($p = 0.06$) increase. This again reflects exposure of the televised films to in-county drivers and the greater exposure to in-county females.

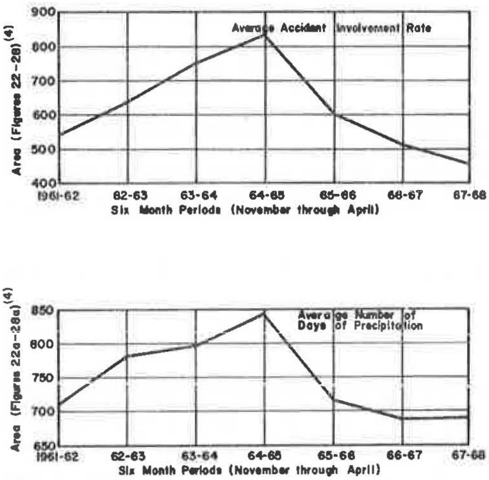

Figure 6. Relationship between accident-involvement rates and precipitation.

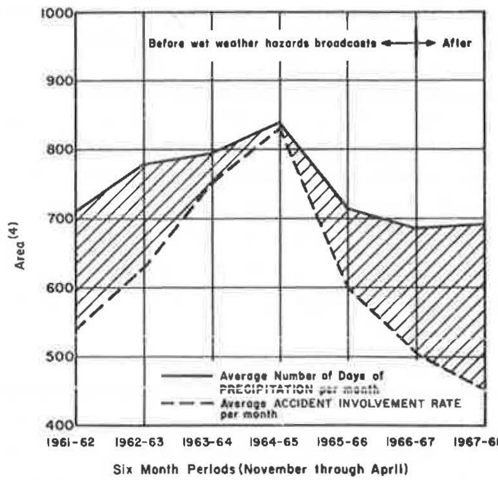

Figure 7. Relationship between accident-involvement rates and precipitation.

A partial explanation as to why this error exhibited an overall increase can be found in the fact that 7 of the 8 intersections are operating at capacity (level of service D) during rush hour traffic, and none has signalized turn phases. The congested conditions force drivers to focus their attention on negotiating turns against a high volume of on-coming traffic. Thus the signaling of a turn becomes secondary to negotiating the turn. Until congestion can be relieved, there is little hope for reducing this error appreciably.

Space does not permit an analysis of factors affecting all the types of errors in Table 7; a more detailed analysis of this and many other aspects of the study are available in report form (4). However, it is important to note from Table 7 that a statistically significant overall decrease in driver errors was achieved in spite of the six limitations listed above.

Accidents

Accidents are intimately related to both driver errors and the ensuing erratic vehicular movements that produce traffic conflicts. The use of traffic conflict criteria to accurately predict intersection accidents has been clearly demonstrated by Perkins and Harris (5). The accident reductions in Table 2 were therefore expected on the basis of early 1967 findings from this study (2), which showed statistically significant reductions in driver errors. It was also expected that the continuing televised driver education films could be designed to produce a beneficial change in the close relationship between local precipitation and local accidents (Fig. 6). A special effort was devoted to the preliminary testing of this hypothesis during the last year of study.

Following the 1967 discovery that monthly accident-involvement rates for the 48 study intersections were closely related to the number of days of precipitation per month, a series of wet-weather driving hazards was presented in the televised films. One film, shown repeatedly, was devoted exclusively to wet-weather driving and slick-pavement conditions. The primary purpose of this effort was to alert drivers to (a) the existence of dry-weather conditioned responses, and (b) the need to reduce speed and increase headway immediately at the beginning of rainfall instead of waiting for that first dangerous situation to force a change in the driver's preconditioning to dry conditions. The beneficial effect of the effort is illustrated in Figure 7.

Prior to the 1967 wet-weather hazards broadcasts, average monthly increases and decreases in the number of days of precipitation per 6-month winter period were always accompanied by like changes in the average monthly accident-involvement rate. An average change of 1 percent in days of precipitation per month from the 1961-1962

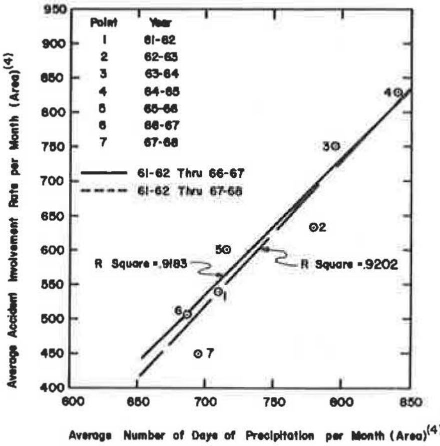

Figure 8. Linear correlation between accident-involvement rates and days of precipitation.

period through the 1966-1967 period was accompanied by a like average change of 0.97 percent in accident-involvement rate and a like average change of 1.09 percent in total accidents. After the broadcasts, the slight increase in average number of days of precipitation per month was accompanied by a continuing decrease in average monthly accident-involvement rate. That is, a 2.5 percent increase in average number of days of precipitation per month (1967-1968 period vs 1966-1967 period) was accompanied by a 6.5 percent decrease in average monthly accident-involvement rate. Although the time periods available for this special effort were considered insufficient for a meaningful statistical test of the hypothesis that the locally oriented candid camera technique is an effective means of changing the wet weather driving habits of local drivers, these results are at least encouraging. They are especially encouraging in view of the fact that all wet-weather hazards broadcasts were made during the period when they had the least exposure to a television audience. It was during this period that the program was dropped from the programming schedule of one local station and subsequently picked up by another local station on a greatly reduced airing schedule. It is expected that the techniques of this study can be used to produce a statistically significant change in the relationship between precipitation and accidents.

There is no precedent in the literature for testing the significance of accident-reducing measures on the basis of a known local relationship between accidents and precipitation. Consequently, the rationale for such an adjustment of accident data is not reflected in the results of statistical tests used in this study. However, in view of the clearly established relationship betweeen precipitation and accidents and in view of the noted change in this relationship, the indication in Table 2, that there is a 0.09 probability of chance occurrence of the 13.0 percent reduction in accident-involvement rate, is presented with considerable reservation. Accident history is probably more closely correlated with slight changes in precipitation than with slight changes in traffic volume. Adjustment of accident data to account for fluctuations in precipitation would be equally as appropriate as adjustment of volume changes (3). There is an urgent need to develop means of collecting the necessary weather data and to set up guidelines for the use of such data in studies based on accident data.

A multiple linear regression analysis was used to determine the correlation between precipitation and accidents before and after the televised special wet-weather hazard films. The data in Table 8 and Figure 8 indicate a good correlation between accident-

TABLE 8

CORRELATION OF AVERAGE MONTHLY ACCIDENT-INVOLVEMENT RATE WITH AVERAGE NUMBER OF DAYS OF PRECIPITATION PER MONTH

Assumed Relationship	Correlation Before (November through April 1961-1962 and 1966-1967)	Correlation After (November through April 1961-1962 and 1967-1968)
Linear	good (R^2 = 0.9183)	good (R^2 = 0.9202)
Semi-log	good (R^2 = 0.9132)	good (R^2 = 0.9187)
Log-log	good (R^2 = 0.9208)	good (R^2 = 0.9070)

involvement rate and precipitation both before and after the special films were televised ($R^2 > 0.90$). Adequate reference to this type of correlation can be found in nontechnical literature (7, 8).

Financial resources available to the project were insufficient for an exhaustive analysis of wet-weather and dry-weather vehicle speeds and headways before and after the special wet-weather driving films. The limited "before" data on local driving habits in wet weather, which were used in final justification of specific emphasis in the televised films, did not represent a sample size sufficient for statistical tests. If planned expansion of this technique to other Kentucky urban areas is successful, the exact nature of the assumed changes in wet-weather driving habits should be determined as a part of the expanded effort.

It should be noted that, because of the change in the relationship between rainfall and accidents, much of the observed decrease in accident-involvement rate (Table 2) may be attributable to use of the special wet-weather hazard films. That is, the benefit from television coverage of the 11 types of driver errors may have been considerably less if the wet-weather driving films had not been used. Almost all roads and streets in the Lexington-Fayette County area of Kentucky become dangerously slick when wet because all pavement surfaces contain limestone aggregate. It is not uncommon to have a rash of accidents during the first hour of rainfall. For example, on November 25, 1967, 25 accidents were reported by Fayette County Police outside of the city during the first hour following the beginning of light rainfall. Any attempt at duplication of the driver-education effort involved in this study should definitely include wet-weather driving hazard emphasis.

Other Effects and Uses of Televised Films

Other effects and uses of the televised driver reeducation films may have been just as beneficial as the effects and uses reported above. Lexington City Police Traffic Division requested and received copies of all the movies for two purposes.

First, they were used to train new police officers. One of the major problems in training new officers is providing recognition of certain types of driver errors. Because the films were made at locations patrolled daily by local officers, they served as ideal training aids. Second, the films were used in Lexington's traffic-violator school. Here they were shown to those traffic violators who preferred attending school in lieu of paying a traffic fine.

Both of these uses served to give the films more widespread exposure to the citizens of Lexington. Increased police attention to the types of driver errors covered in the televised program probably served to reinforce both the effects of the program and its viewing audience. Increased police attention to the accident potential of traffic conflicts covered in the films probably increased the accident reporting rate (9), thereby minimizing the apparent accident-reduction benefits of the program.

During the spring of 1967, the movies were shown at a number of local 4-H driver-training classes, and, on one occasion, they were shown to a high school physical education class. In the spring of 1968, three of the films were used in a science fair held at Ashland, Kentucky. Sample films and interim results from the study were presented, by request, at meetings of 16 different local civic and professional organizations during 1967 and 1968. It is extremely doubtful that very many local citizens failed to see or hear of the program.

CONCLUSIONS

The televised, locally oriented driver reeducation program was effective in reducing driver errors and accidents. Statistically significant reductions of 17.4 percent ($p < 0.01$) in driver errors per 1,000 vehicles and 12.5 percent ($p < 0.01$) in total accidents were achieved.

The magnitude of driver error change varied considerably with the 11 types of driver errors according to (a) the amount and type of television coverage of each error, (b) the extent to which local intersection conditions encouraged adjustments of driver habit related to each error, and (c) the amount of exposure of the televised films to various segments of the driver population.

In consideration of the traffic safety potential, this driver reeducation technique should be adopted in every major urban area in this country as rapidly as available resources will permit. The cost would be considerably less than the costs involved in many of the questionably effective current approaches to driver education (10, 11).

Continuous, frequent, and regular airing of the locally televised films is recommended. Beneficial effects from such a program will otherwise dissipate with time. Because of the need to develop a lasting interest on the part of television viewers, entertainment is one of the most important aspects of production.

In public reference to the use of driver-education techniques, the term "driver education" should not be used except in connection with the beginning driver. Many of the past and present driver-education efforts are so distasteful to the average driver that he is often repulsed, not educated, and not often entertained. For all except the beginning driver, we need driver awareness or driver reeducation efforts, not driver education. Drivers already know "how to drive"; they are not aware of the traffic madness created by their mistakes—mistakes that are almost always forgiven by themselves, by the laws of probability, and by the urge for survival on the part of other drivers, but not by the candid camera.

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The Effects of Sight Distance and Controlled Impedance on Passing Behavior

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The purpose of this research was to determine the singular and combined effects of impedance distance, impedance speed, passing sight distance, and traffic volume on driver acceptance of passing opportunities as they occur on rural two-lane highways. A further aim was to describe empirically the effects of these variables on the nature of the passing maneuver.

The report presents a detailed discussion of the methodology, test sites, instrumentation, experimental procedures, and major results. Controlled road tests were designed such that the subject driver was unaware that he was involved in an experiment. An experimenter-controlled, instrumented van produced and regulated the impedance conditions. Passing sight distance was controlled through test site selection, and traffic volume at the test sites was treated as a sampling variable.

The major results indicate that passing sight distance is the predominant variable that influences the decision to pass. An analysis of covariance, in which the effects of traffic volume were controlled, yielded statistically significant effects for impedance speed and the impedance-distance/sight-distance interaction.

•THE RESEARCH presented here is part of an overall program of the Bureau of Public Roads that is aimed at better definition of driver overtaking and passing behavior. The results reported are from the first experiment of a study sponsored by the Bureau under Contract No. CPR-11-4092 and designed to quantify several of the determinants of driver passing behavior on rural two-lane highways. An additional aim of the research was to empirically describe the effects of selected variables on the nature of the passing maneuver.

A specific goal was to examine the influence of the singular and combined effects of impedance speed, impedance distance, and traffic volume on the acceptance or rejection of a passing opportunity where passing sight distance is restricted by the horizontal and/or vertical curvature of the highway. A further purpose was to determine the effects of sight distance on various elements of the passing maneuver.

Because additional analyses of the data are currently in process and because the remainder of the overall program will involve the study of independent variables that can be expected to interact with those studied in this first experiment (e.g., lead vehicle speed), no attempt will be made to draw firm conclusions from the data presented here. Similarly, comparisons between the results obtained in this study and the findings available in the literature will be presented in a more comprehensive final report.

Paper sponsored by Committee on Operational Effects of Geometrics and presented at the 48th Annual Meeting.

METHODOLOGY

The general methodology used to implement the research involved the use of an experimenter-controlled, van-type vehicle that was instrumented to facilitate the observation and recording of appropriate measures. The van was driven over selected test sites that were characterized by a specified passing sight distance in the passing zone and that had, prior and adjacent to the passing zone, a sufficiently long area of inadequate passing sight distance within which to impede subject drivers. Figure 1 is a schematic representation of a test site that illustrates the interaction between subject and experimenter vehicles. The impedance areas were striped and officially signed as no-passing zones in order to discourage the subject driver from prematurely passing the experimenter vehicle. In other words, a test site was created on which a subject driver was impeded for a specified distance at whatever speed the experimenter vehicle was driving, and was subsequently faced with a geometrically restricted passing opportunity. This, in effect, simulated the situation in which the driver is the fourth or fifth vehicle in a queue and must follow slower moving traffic for some period of time before being able to pass.

Experimental Procedure and Instrumentation

An operator equipped with speed measurement and communications equipment was located at a point upstream of the impedance zone. Depending on the experimental condition, the instrumented van was positioned a short distance from the beginning of the 1-, 3-, or 5-mile impedance zone. On reception of a "ready" signal from the van, the spot-speed measurement was taken at the first opportunity, i.e., on arrival of the next appropriate vehicle. The following types of vehicles were accepted as subject vehicles: American and foreign sedans, convertibles, and station wagons; sports cars; and pickup and panel trucks. A trial began when one of these vehicles approached the

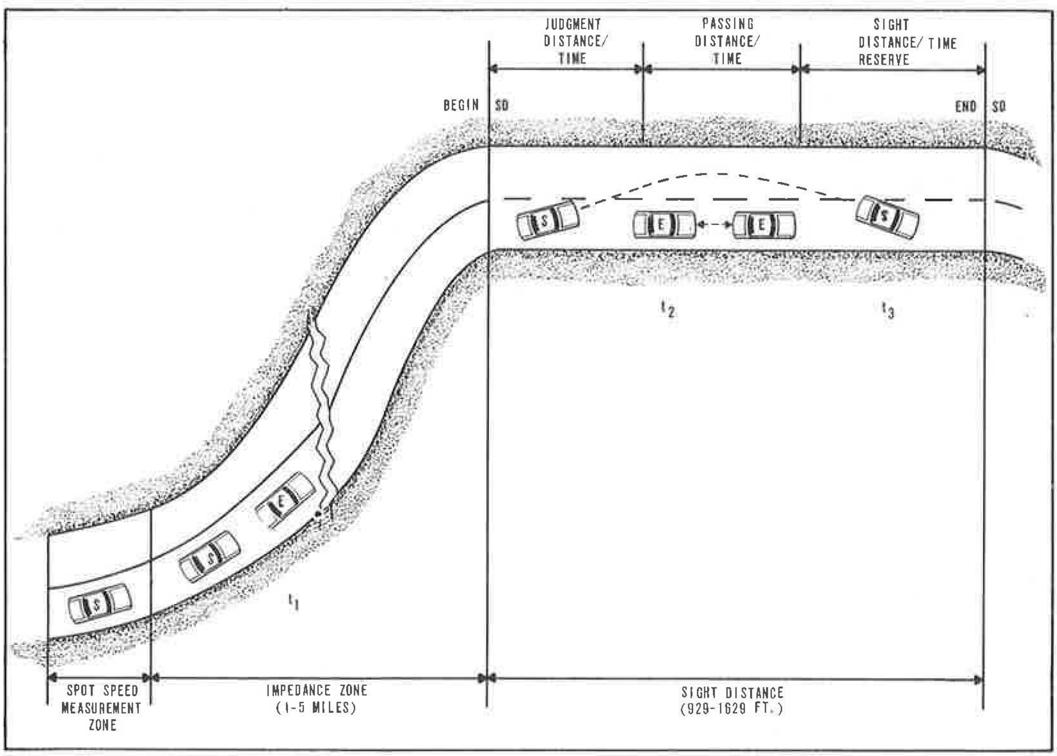

Figure 1. Test site (schematic).

Figure 2. Interior of van (rear view).

beginning of the impedance zone. The spot-speed and a description of the subject vehicle was radioed to the van, which then pulled out onto the highway ahead of the subject vehicle, gradually accelerated to the predetermined speed, and subsequently established impedance. The van continued at this speed until reaching a point approximately $\frac{1}{4}$ mile before the beginning of sight distance, at which point the speed was gradually adjusted to 35 mph. A constant speed through the passing zone for all subject vehicles was necessary so that the results would not be confounded by the effects of the lead vehicle's speed during the passing maneuver itself. In this way risk varied only as a function of the sight distance. On reaching the location $\frac{1}{4}$ mile before the beginning of sight distance, the driver of the van made radio contact with a flagman positioned at the end of the passing zone (and out of sight of the subject driver) to indicate that opposing traffic should be stopped. The van then continued through the passing zone collecting the necessary data.

Figure 2 shows the interior of the experimenter van, which was equipped with a one-way mirror system installed in the rear of the van to prevent the subject driver from seeing into the rear window. Through the use of another mirror system, the rear of the van was made to appear to be loaded with boxes.

An operations recorder was used to record impedance time, judgment time, and passing time. Mounted in the front and rear of the experimenter van, 16-mm cameras recorded the passing distance and judgment distance data. The film data were subsequently reduced to numerical form by measuring the position of the subject vehicle relative to reference markings put on the centerline of the highway and recorded on the film. A distance catalog of these references relative to the beginning and end of sight distance permitted the distance involved to be accurately determined from the photographs.

Test Sites

Because certain characteristics of the test sites chosen for the research are critical to the interpretation of results obtained, some of the problems of test site selection deserve mention at this point. The site selection criteria used were as follows:

1. The impedance zones adjacent to the passing zones in which the measurements were being taken had to be a minimum of 5 miles in length, have no signed speed zones, and have no major intersections or other characteristics such as commercial or industrial complexes that could influence vehicle speeds or queue buildup. In order to provide a 5-mile impedance zone, it was necessary to eliminate all passing zones in the impedance area. Appropriate striping and signing procedures consonant with practices of the Pennsylvania Department of Highways were used.
2. The passing zone of test sites had to have a specified distance within the 900- to 1,700-ft range, with a gradient restriction of 5 percent or less. Further, as the subject driver entered the site, the entire sight distance had to be available at a well-defined point and the decrease in sight distance had to approximate a linear function as the subject driver traversed the passing zone to a point near the end of the initially available sight distance.

The characteristic of monotonically decreasing sight distance was necessary because there was no control of the subject population to eliminate local drivers. If the decrease in sight distance is not monotonic (e.g., if it decreases to a point and then increases again), the local driver, who knows that particular section of highway, may begin the pass knowing that he will be getting more sight distance information before he has to finally commit himself to the pass. The nonlocal driver, on the other hand, will make the decision to pass on the basis of the initial sight-distance information. Selecting sites on which there is a monotonic (and in fact, nearly linear) decrease throughout the site requires both the local and nonlocal drivers to utilize the same sight-distance information in making the decision to pass.

Independent Variables

Sight Distance—The study was conducted over a total of five test sites, each representing one of four different levels of passing sight distances: 929, 1,086, 1,363, and 1,629 ft. Several studies in the passing-behavior literature indicate that the 929-ft site was sufficient as a minimum. The use of the 1,629-ft maximum was based in part on the literature and in part on pilot observations made early in the study. It is felt that an adequate range of "restrictive" sight distances was sampled.

Impedance Distance—Impedance distance is defined as the distance over which a subject driver is forced to follow the experimenter vehicle until there is a passing opportunity. Distances of 1, 3, and 5 miles were used in the study.

Impedance Speed—Impedance speed is defined as the speed at which the subject driver was forced to drive over the impedance distance. Three levels of impedance speed, corresponding to a 10, 20, or 30 percent reduction in the speed desired by the subject driver, were used. To ensure a high degree of experimental control over the impedance speed variable required that an estimate be made of the desired speed of each subject driver as he traversed the test site. The reason is that if the experimenter van were traveling at a speed faster than that desired by the subject driver, there obviously would be no impedance condition imposed. To establish the desired speed of the subject, an observer made a spot-speed measure at a point near the beginning of the appropriate impedance zone. This speed was communicated by radio link to the experimenter in the data collection van, who subsequently established a lead vehicle speed (impedance speed) that was 10, 20, or 30 percent less than the spot speed.

Traffic Volume—Because traffic volume on the test sites could not be controlled, it was treated as a sampling variable. Volume was measured continuously during data collection, and the ½-hour volume immediately preceding each trial was noted.

Dependent Variables

The dependent variables in the study were of two types: discrete and continuous. The discrete data collected were passing frequency and abort frequency under each of the experimental conditions. In order to determine the extent to which the independent variables affected the nature of the passing maneuver, judgment time and distance, passing time and distance, and sight distance reserve were measured.

Judgment time (or distance) is the interval between the arrival of the subject driver at the beginning of sight distance and the initiation of the passing maneuver. Passing distance is self-explanatory. However, it should be noted that the initiation of a pass was defined as that point at which the right front tire of the subject vehicle crossed the centerline of the highway. A situation in which this occurred but was not followed by a completed pass was defined as an abort. The end of a pass was defined as that point at which the right rear tire of the subject vehicle crossed the centerline, having passed the experimenter van. Sight distance reserve was the interval in units of time and distance from the end of the pass to the end of sight distance.

Factors such as sex of driver, number in vehicle, vehicle type, state of registration, number of children, and sex of other occupants were also noted for each subject vehicle.

Experimental Design and Analysis

The sight distance, impedance distance, and impedance speed variables were arranged factorially in a 5 by 3 by 3 matrix; i.e., a 3 by 3 matrix for each of five test sites. The complete factorial design permits all interactions to be tested.

The desire to test all interactions of the independent variables dictated that analysis of variance techniques be employed. However, the dependent variable of primary interest is the acceptance or rejection of a passing opportunity, a dichotomous variable for which the underlying probability model is the binomial distribution. Thus the assumptions of normality and homogeneity of variances, necessary to the use of analysis of variance, were violated. For this reason an arcsin transformation was applied to the dichotomous data. Given the arcsin transformation

$$y = 2 \arcsin \frac{x}{n}$$

it can be shown by appealing to the central limit theorem that y is approximately normally distributed with a mean $2 \sin^{-1}(p)^{1/2}$ and variance $1/n$. In this experiment, n is the number of subject drivers under any given condition, and x/n is the proportion of drivers that passed (it is also the probability that a driver will pass).

In other words, the arcsin transformation is such that within each cell the transformed variable y is nearly normal with an approximate homogeneous variance of $1/n$, where n is the number of observations in each cell. Within each cell the n observations give rise to one transformed observation y. For each level of impedance speed, the total number of transformed observations is obtained by collapsing across the impedance distance and sight distance variables. Thus, the total number of observations for each level of impedance speed was $3 \times 5 = 15$. The same is true for each level of impedance distance. Similarly, the total number of transformed observations for each level of the sight distance variable was $3 \times 3 = 9$.

It may be noted that a total of 1,462 observations were made, a minimum of 30 per cell. It can be shown that 30 observations per cell provide a guaranteed power of 0.90 for a given Type I error of 0.05. This power guarantee is based on an assumed overall treatment effect of approximately 0.10 for impedance conditions and approximately 0.15 for sight distance. For all significant F-ratios in the analysis of variance, Scheffé's (1) method of multiple comparison was used to identify the specific source of significant treatment effects.

Because traffic volume had to be treated as a sampling variable, it was handled as a covariate in order to provide a more refined and accurate analysis of treatment effects. Although the covariate was well defined, the analysis of covariance had to be modified to handle the dichotomous aspect of the dependent variable. As in the analysis of variance situation, the arcsin transformation was used. However, because the result of this transformation combines the "pass, no-pass" observations in each cell into a single observation on the transformed scale, a problem arises because the covariate assumes a number of different values for each observation. If there were replication within each cell, the problem could be solved by using the average of these values as a covariate. However, the lack of replication dictates that another solution be used. The best approach appeared to be to obtain two transformed observations from each original cell by dividing the total observations in the cell on the basis of the magnitude of the corresponding traffic volumes; that is, one of the two observations corresponding to the higher traffic volume and the other to the lower. Because it was desirable to keep the number of subjects per cell as large as possible, more than two transformed observations per cell did not seem feasible. Even though this method results in only half as many observations per cell as compared with the analysis of variance situation, it is felt that the number of observations per cell is sufficiently large to permit the assumption of normality in the transformed observations.

RESULTS AND DISCUSSION

Before proceeding into a discussion of the results obtained, a potentially important point about the sample deserves mention. It will be recalled that the section of highway over which subject drivers were impeded was striped as a "no-pass" zone so that control could be maintained over the impedance distance. In order to produce a sufficiently long impedance area, it was necessary to restripe some sections that were previously passing zones—for example, sections with sight distances in excess of 800 ft. Although this was undesirable, it was believed better to accept this flaw than to compromise on other, more important criteria for site selection.

It was assumed that the double striping and no-passing signs would prevent much of the passing occurring before the test site passing zone. However, the number of "premature" passes, i.e., passes made before the test site passing zone, was sufficiently large that it may have affected the nature of the sample from which the statistical inferences are drawn. That is, the premature passers may well be more aggressive, or less frustration tolerant, than those drivers who were willing to follow the experimenter van throughout the entire impedance zone. In this case, it is probable that a larger proportion would have passed in the passing zone had they reached it. The fact that these drivers are not included in the sample on which these results are based may, in effect, have resulted in a sampling bias favoring the more conservative drivers. The importance of the foregoing discussion of premature passers will become apparent as the discussion of results progresses. The formal analysis of premature passes will be presented in a future research report.

Another limitation that deserves mention is the temporary exclusion of an analysis of the effects of impedance on the continuously distributed dependent variables. The rationale for the exclusion was the analysis of the discrete data showing that the impedance variables contributed a very small portion of the total variance. Given acceptance of the assumption that impedance-produced frustration provides the driver with a "set" and that final acceptance or rejection of the passing opportunity is based on information presented at the beginning of the passing zone (i.e., sight distance and lead vehicle speed information), then it would be expected that impedance effects would contribute even less variance to those variables descriptive of the passing maneuver. However, in the interest of completeness these analyses will be performed and will also be included in future reports.

Discrete Data

The observed increase in passing frequency as a function of sight distance is shown in Figure 3. Although the trend is as expected, the absolute frequencies may be low because of the exclusion of premature passers from the sample. Even though there are no baseline data in the literature as to passing frequency as a function of geometrically limited sight distance, it is interesting to relate our findings to those of Farber and Silver (2) who performed an observational study on a two-lane highway in which the

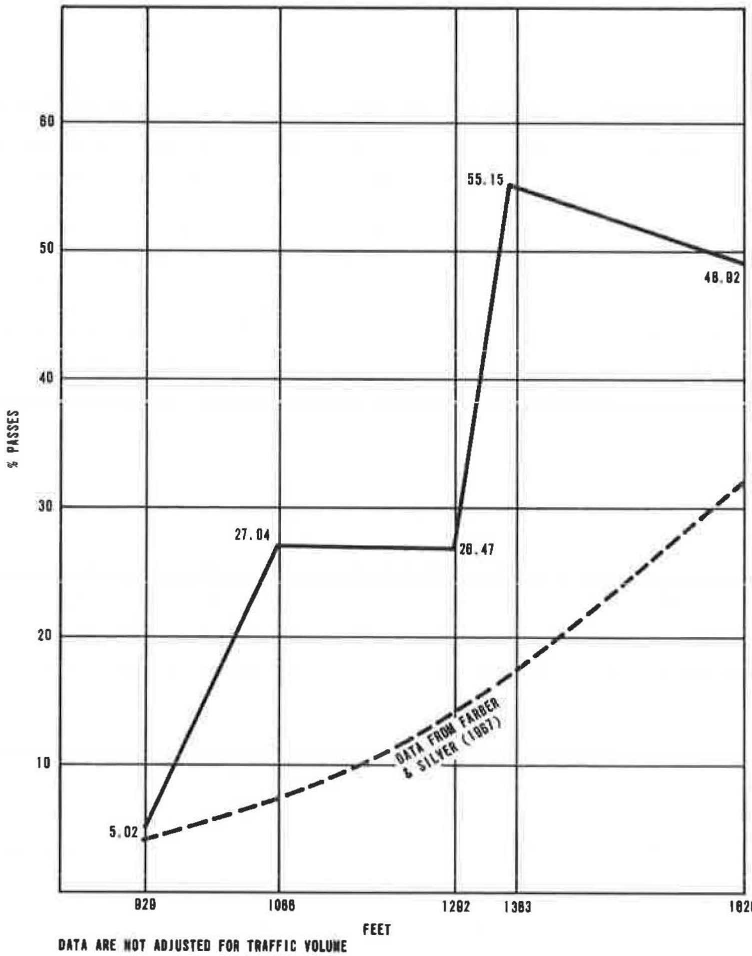

Figure 3. Sight distance.

passing opportunity was restricted by an oncoming vehicle. Although the restricted passing opportunities differ in definition (i.e., geometrics vs the presence of an oncoming vehicle), there is in general corroborative evidence showing that as the sight distance opportunity increases, so does the probability of a pass. Again the studies are not directly comparable, but there is in both cases a requirement for the potential passer to evaluate the risk involved in accepting a passing opportunity. Although the trends are similar, it is likely that the differences in magnitude between the two sets of data reflect a differential perception of risk; i.e., in the Farber and Silver situation the probability of an oncoming vehicle was unity in all cases (2), whereas in our study the potential passer had to estimate the probability of an oncoming vehicle. The risk factor and the conservative performance in the Farber and Silver study were undoubtedly compounded by the fact that the drivers dealt with a closing rate consisting of two vectors, one of which was, of course, not subject to their control, whereas in our study the closing rate in the absence of opposing traffic was determined by the speed of the potential passer.

The analysis of variance performed on the major independent variables indicated that when the effect of traffic volume is not statistically controlled, sight distance produces the only statistically significant (P = 0.01) treatment effect. In Table 1 the statistic omega-square shows sight distance accounting for 79 percent of the total variance (3). Comparisons of individual pairs of test sites (sight distance) by the Scheffé method indicate that the differences between sites 2 and 3 and between sites 4 and 5

TABLE 1

ANALYSIS OF VARIANCE

Source		Degree of Freedom	Sum Squares	Mean Squares	F-Ratio	Required F-Ratio P < 0.01	Required F-Ratio P < 0.05	Omega-Square
Sight distance	(A)	4	8.555293	2.138823	61.029[a]	4.77	3.01	0.79
Impedance distance	(B)	2	0.180139	0.090070	2.570	6.23	3.63	0.01
	(AB)	8	0.571020	0.071378	2.037	3.89	2.59	0.03
Impedance speed	(C)	2	0.245389	0.122695	3.501	6.23	3.63	0.02
	(AC)	8	0.364740	0.045593	1.301	3.89	2.59	0.01
	(BC)	4	0.109017	0.027254	0.777	4.77	3.01	0.00
Error		16	0.560742	0.035046				
TOTAL		44	10.586340					

[a]P = 0.01

are not significant, but that all other comparisons are significant. As shown in Figure 3, there are reversals in passing frequency between these two sets of sites.

The regression analysis performed to obtain adjusted means for the analysis of covariance indicated that traffic volume was significantly correlated (P = 0.01) with passing frequency. The results of the covariance analysis (Table 2) indicated that removal of the effects of traffic volume yields, in addition, a significant impedance speed treatment (P < 0.05) and a significant impedance distance/sight distance interaction (P < 0.05). Apparently traffic volume masked the effects of impedance speed and the impedance distance/sight distance interaction, and the increased degrees of freedom in the covariance analysis made the design more sensitive to departures from the null hypothesis.

Although traffic volume would be expected to affect the probability of a pass, the actual volumes of the high and low categories in our sample are not, from a traffic engineer's point of view, strikingly different; e.g., a range from 16 to 86 vph (vehicles per hour) is fairly typical. From a human performance point of view, however, such differences apparently have operational significance. Because a large portion of the drivers in this experiment may have been local drivers, they would be expected to have experienced extended exposure to the volume conditions existing on the roads where the

TABLE 2

ANALYSIS OF COVARIANCE

Source		Degree of Freedom	Sum Squares	Mean Squares	F-Ratio	Required F-Ratio P < 0.01	Required F-Ratio P < 0.05	Omega-Square
Sight distance	(A)	4	17.518461	4.379615	73.628[a]	3.65	2.52	0.72
Impedance distance	(B)	2	0.345440	0.172720	2.904	4.98	3.15	0.01
	(AB)	8	1.211504	0.151438	2.546[b]	2.82	2.10	0.03
Impedance speed	(C)	2	0.461492	0.230746	3.879[b]	4.98	3.15	0.01
	(AC)	8	0.697486	0.087186	1.465	2.82	2.10	0.01
	(BC)	4	0.184877	0.046219	0.777	3.65	2.52	0.00
Error		60	3.568967	0.059483				
TOTAL		88	23.988227					

[a]P = 0.01 [b]P = 0.05

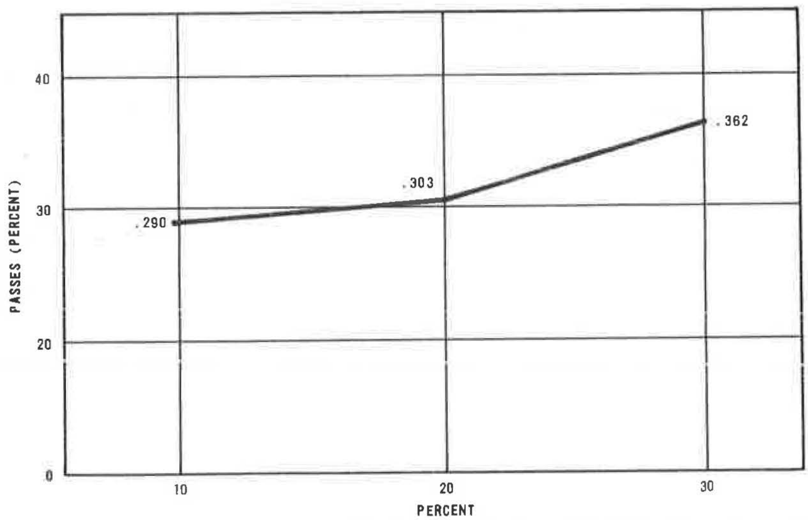

Figure 4. Impedance speed.

test sites were established, and their driving habits would have been adjusted as a result of this exposure history. In effect, drivers appear to develop a personal set of values as to what constitutes high and low volumes on a particular road. It is well known, from studies in experimental psychology, that when an individual is exposed to a range of stimulus conditions, he develops an internal scale that is consequently used to evaluate other stimuli lying between the extremes. For instance, if a driver is routinely exposed to volume levels between 20 and 80 vph, a volume of 65 vph will be considered high. On the other hand, an individual who drives on roads on which the volume varies from 60 to 300 vph would consider 65 vph as a very low volume. Given the range of volumes observed on our test sites, a difference between 34 and 59 vph could be highly significant in terms of its effect on driver passing behavior.

The significant effect of speed impedance is evidence for the development of frustration because the driver is being impeded. Figure 4 indicates that, as hypothesized, the greater the level of impedance, the higher the frustration and the greater the probability of passing. It should be noted, however, that the Scheffé comparisons indicated a nonsignificant effect between 10 and 20 percent impedance conditions, and although the main effect is statistically significant, it accounted for only a little over 1 percent of the variance. Because spot speed was used as an estimate of average speed (desired speed) in establishing the level of impedance, this result could possibly have been obtained due to the imperfect relationship between the two measures. That is, the percentage values attached to each level may be, for example, 0, 10, and 20 percent rather than those planned. As will be discussed later in more detail, the adequacy of spot speed as a predictor of average speed is currently being assessed.

Both the lack of a main effect for the distance impedance variable and the presence of the sight-distance/distance-impedance interaction may be due to the premature passes. Over a 5-mile impedance there are more opportunities for a premature pass than over a 1-mile impedance. This is reflected in the number of premature passes that occurred at each level. For example, the number of premature passes at each level of distance was as follows: 1-mile, 46; 3-mile, 152; and 5-mile, 171. Because the premature passers are likely to be drivers who have a lower tolerance to frustration and/or are more aggressive, it is apparent that the 5-mile sample contained proportionally fewer drivers with these characteristics. Thus, based on an impedance-produced frustration hypothesis, one would expect fewer passes from that sample. The data presented in Figure 5 seem to bear out this contention. The anslysis of the premature passes will

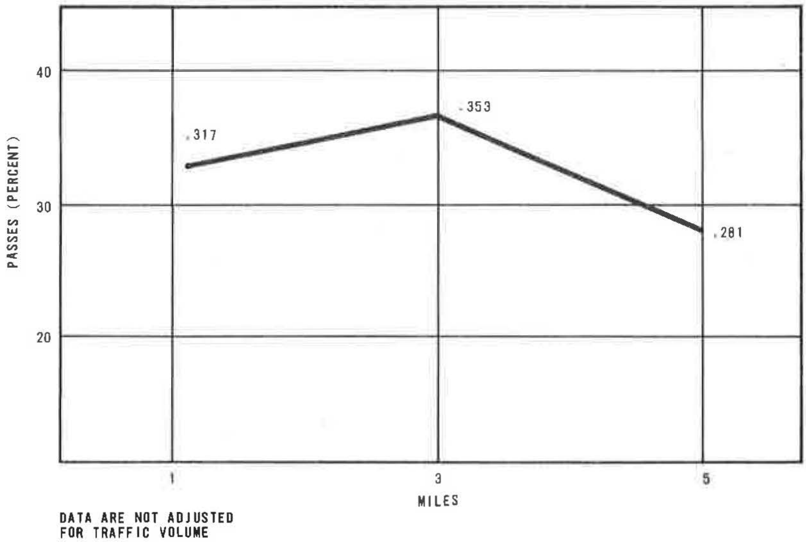

Figure 5. Impedance distance.

provide a more accurate answer to the question. It may also explain the interaction observed, in that the premature passes are not equally distributed across test sites.

Continuous Data

A one-way analysis of variance was performed to assess the effects of sight distance on each of the six dependent variables. Because the degrees of freedom associated with each measure were equivalent, the required F-ratio ($F_{5, 100} = 3.20$) for $\alpha = 0.01$ was also the same. Although the F-ratios were all significant beyond the 0.01 level, the magnitude of sight distance effect (omega-square) varied widely across the different dependent measures.

Given a statistically reliable treatment effect in each case, the Scheffé method of contrast was used to determine what additional inferences could be drawn regarding

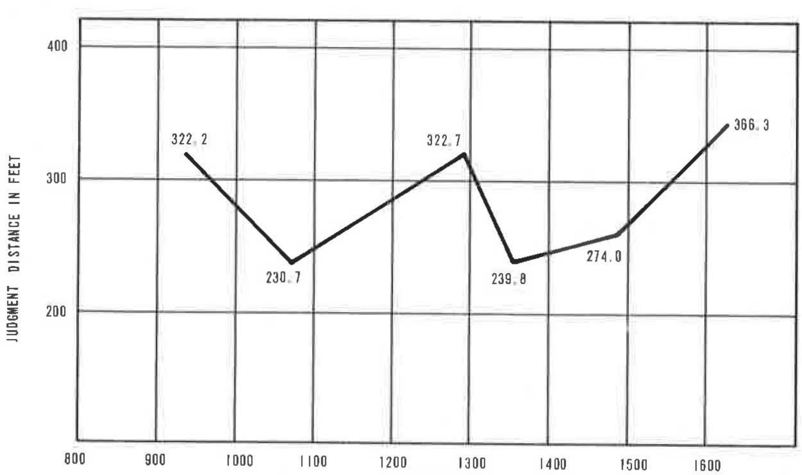

Figure 6. Mean judgment distance for all levels of sight distance.

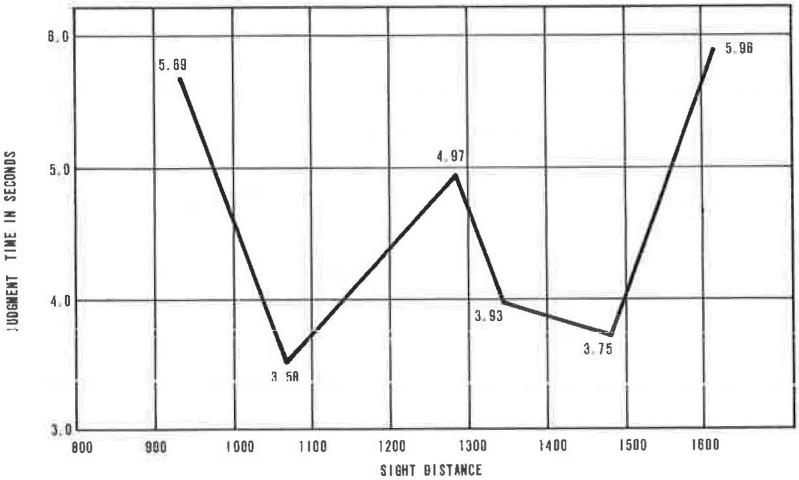

Figure 7. Mean judgment time for all levels of sight distance.

differences between individual sets of means. The results of the individual comparisons are discussed in conjunction with each of the dependent variables. The presentation and discussion of results is divided into separate sections, each covering the time and distance measures for the elements of the passing maneuver, i.e., judgment, passing, and reserve.

Judgment Data—Although the F-ratios for judgment time (F = 6.36) and judgment distance (F = 7.57) indicate that sight distance produces a statistically significant treatment effect, the shape of the function obtained (Figs. 6 and 7) makes the data rather difficult to interpret. Crawford (4) found that the relationship between decision time and the difficulty of the passing situation was defined by a U- or V-shaped function. In his study, an opposing vehicle was used to produce the levels of restriction (or passing difficulty). If perceived risk in the oncoming vehicle situation is similar to perceived risk where restriction is produced by highway geometry, one would expect a similarly shaped curve when plotting judgment time against sight distance. As seen in Figures 6 and 7, the judgment time and distance values that are most similar are those at the extreme ends of the sight distance range sampled; this suggests that the observed function may be similar to the relationship obtained by Crawford. However, two factors prevent this from being anything but suggestive at this point. First, the Scheffé comparisons for both the time and distance data indicate that the differences observed between sites 1 and 2 are not significant. A plausible explanation for the lack of significance is that the means for site 1 were computed from only four observations that would, of course, require an extremely large difference to obtain significance at the 0.01 or 0.05 level with so few degrees of freedom. It should be noted that two data collection vans were used in order to increase data collection rate. However, because the sample size required was much less for the continuous data, only one of the vans was instrumented. The small sample for site 1 was due to the small number of passes observed (i.e., 15) and the chance occurrence that the noninstrumented van was involved in the majority of these (i.e., 11).

Another consideration that restricts the postulate of a U-shaped function to speculation is the increase in time and distance values between sites 2 and 3. Again the Scheffé comparison indicated that the increase was not significant at the 0.05 level. However, because it was not possible to find a set of test sites that matched perfectly in all respects, a number of intrasite differences were considered in an attempt to explain why an increase might be observed. The factors considered were gradient in the approach to the passing zone or in the initial part of the zone, and proximity of the passing zone to a town. It was felt that the gradient factors may have affected vehicle

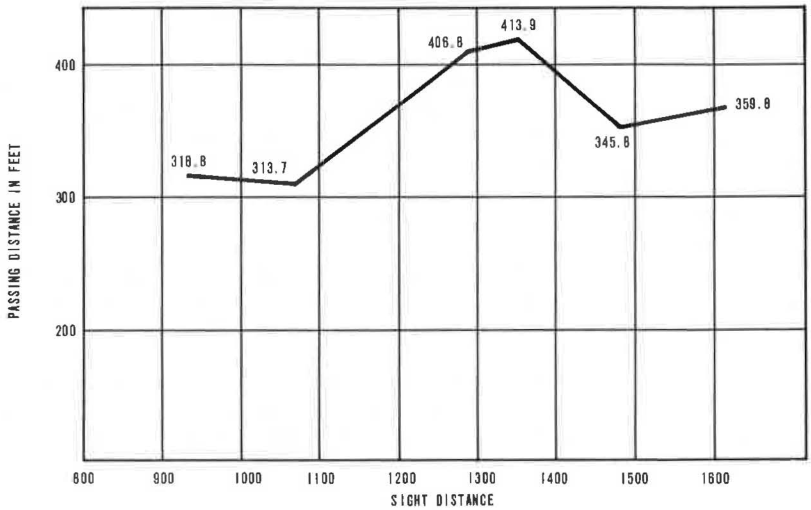

Figure 8. Mean passing distance for all levels of sight distance.

acceleration capability to the degree that it would be perceptible to the driver and would, therefore, make the decision to pass more difficult. Consideration of the second factor was based on a utility hypothesis. That is, if a town were near the end of the passing zone (i.e., within one mile), the estimated utility of a pass may be negligible because the time loss or frustration incurred by continuing to follow the lead vehicle would be small if that town were the driver's destination. The hypothesis that the driver attaches a utility structure to the decision to pass and evaluates the costs and their associated probabilities is certainly tenable.

Although an analysis of intrasite differences indicated that none of the factors mentioned above could alone be expected to account for the increase in judgment time, site 3 was the only one that contained all three of the characteristics noted; i.e., it was approximately 0.5 miles from the nearest town, it had an approach gradient of approximately 7 percent, and it had a slight upgrade over the entire passing zone.

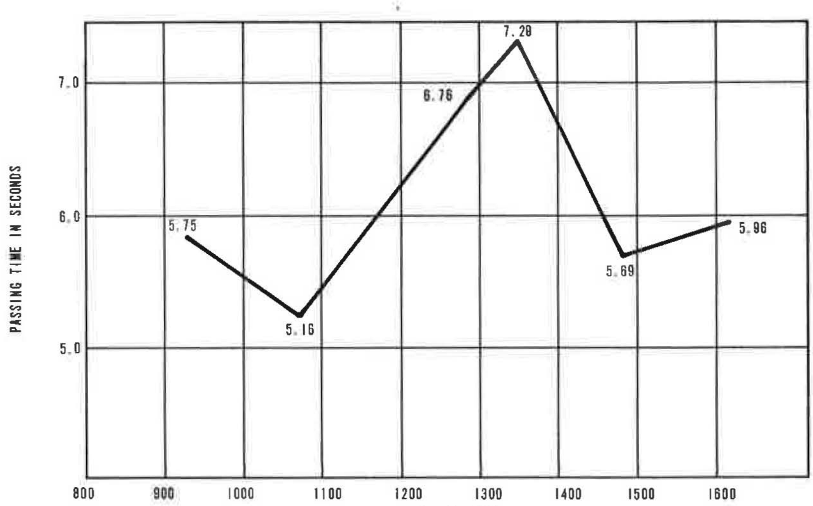

Figure 9. Mean passing time for all levels of sight distance.

The factors taken together may have caused an increase in judgment time and distance.

The foregoing discussion was not offered as an interpretation of the data obtained, but rather to indicate the possible influence of certain test site characteristics that were previously felt to be relatively unimportant in terms of the dependent variables used. Because minor differences between test sites may have caused the apparent lack of orderliness in the data, it is clear that in future research on the passing problem, the test site selection criteria must be made even more stringent than those used in the current study.

On the basis of individual Scheffé comparisons, it was determined that the significant differences were produced by test sites with no particular geometric problems; hence, it is fairly safe to assume that the primary determinant of the difference was sight distance.

Passing Data—The F-ratios for passing time (F = 3.95) and distance (F = 4.99) were both significant at the 0.01 level. However, as with the judgment data, there are difficulties in interpretation in that these variables do not appear to be monotonically related to sight distance (Figs. 8 and 9).

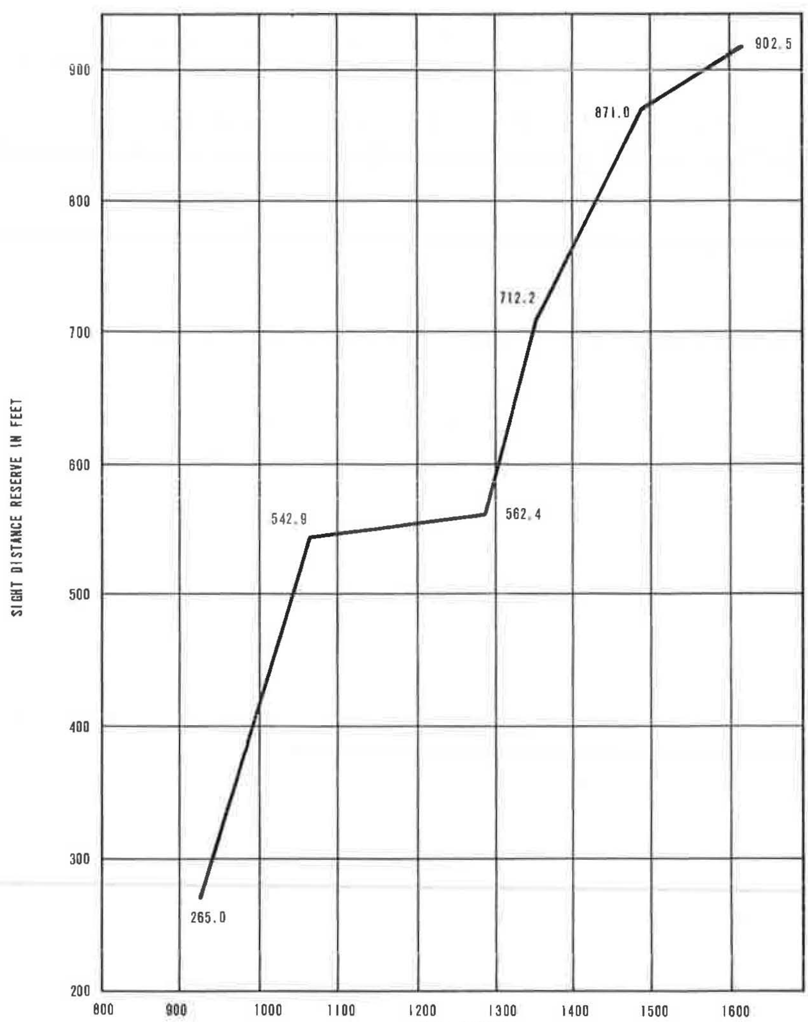

Figure 10. Mean sight distance reserve for all levels of sight distance.

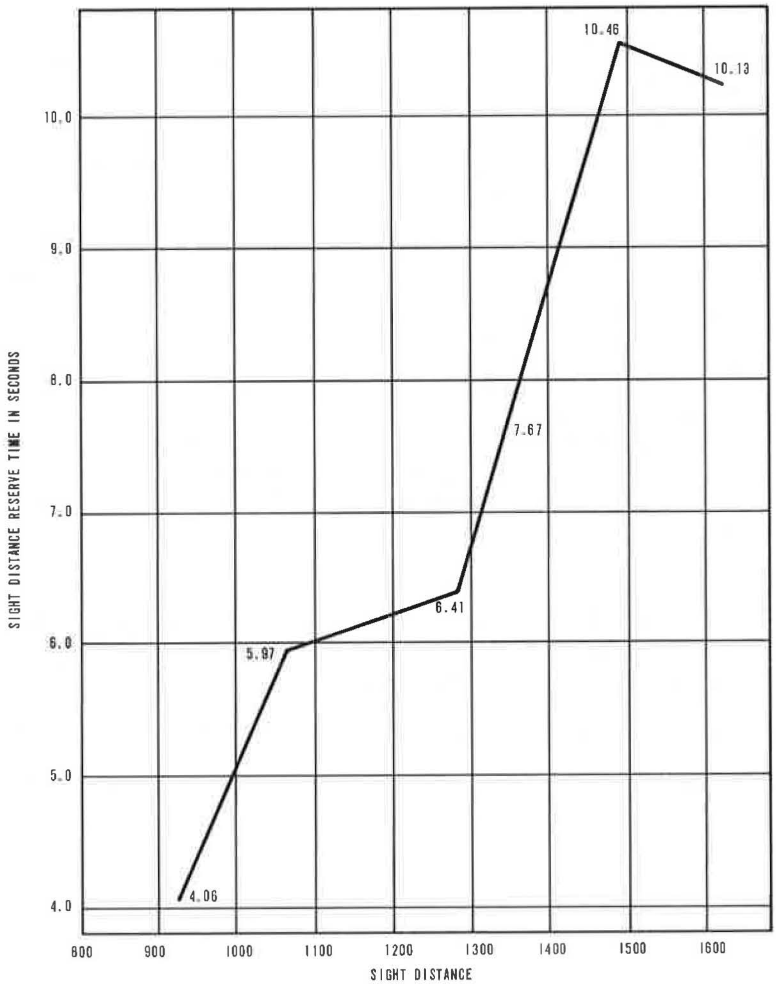

Figure 11. Mean sight distance reserve time for all levels of sight distance.

It is not unreasonable to postulate that within a range of restrictive sight distances, the driver passes as quickly as possible to minimize the probability of meeting an oncoming vehicle. The relatively small sight distance reserves observed at the shorter sight distances tend to support this position.

Sight-Distance Reserve Data—Measures of both time and distance were significant at the 0.01 level, with F-ratios of F = 11.02 and F = 51.98 respectively. It should be noted that although the distance reserve could be measured accurately from the films and test site reference maps, the reserve time data, in comparison to other dependent variables, may contain more measurement error. These measures required that the van operator estimate visually when the subject vehicle reached the end of sight distance. Therefore, the longer distance reserves probably resulted in some error in the reported reserve time estimates.

As would be expected from the small absolute variation in the judgment and passing data, sight distance reserve increases in an almost linear fashion as sight distance increases (Figs. 10 and 11). The omega-square estimates of variance indicate that sight-distance reserve in feet is the dependent variable most affected by sight distance variation. Sight distance accounted for 68 percent of the variance when the dependent measure was reserve distance.

SUMMARY

It is obvious from analysis of the discrete data that, of the variables studied, sight distance is the most influential determinant of the probability that a driver will accept a given passing opportunity. However, when the data were adjusted for the effects of traffic volume (by covariance techniques), impedance speed and the sight-distance/impedance-speed interaction were significant at the 0.05 level. In terms of the proportion of the total variance accounted for by these latter variables, their operational significance is questionable.

With respect to the continuous data, the relatively small absolute variation in the judgment and passing data, and the essentially monotonic relationship between sight-distance reserve and sight distance suggest that driver passing behavior is fairly consistent regardless of sight distance. One tenable explanation is that, within the range of restrictive sight distances studied, drivers generally pass as quickly as possible.

Another major variable that the authors feel will have a significant effect on acceptance of passing opportunities and the nature of the passing maneuver is that of lead vehicle speed. A current research effort is directed toward determining the main and interactive effects of this variable with those assessed in the current study. For this reason, a discussion of the engineering applications of the results will be reserved until these data are available.

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Velocity Sensing—Comparison of Field and Laboratory Methods

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This paper compares the effect of varying the sensory input (visual, auditory, kinesthetic, tactile, and vestibular cues) on the appreciation of traveled velocity. A movie technique was developed to remove the effects of acceleration and to present controlled frontal and peripheral visual cues. The range of velocities was extended to 100 mph.

It is concluded that (a) the removal of the force-sense feedback mechanism acts to reduce the ratio of the estimated to the presented or actual range of velocities; (b) there is direct variation of the absolute error with velocity as the range is extended to include high speeds; and (c) sensing of velocity based on peripheral visual stimulation appears to be more resistant to experimental artifacts, such as a monotonous environment, fatigue, and the beta effect (apparent movement produced by an increase of illumination of part of the field), than frontal visual stimulation.

A methodological confusion in plotting velocity sensing data when using the methods of estimation and production is pointed out as influencing the description of such data in terms of over-estimation and under-estimation.

•ANALYSES of the driving task generally place heavy emphasis on the visual input. For example, Allen (1) centrally locates the eye as the receptor to interface the environment and to discriminate position, direction, and speed. Similarly, Cumming (2) defines visual as the input to the perceptual and computer mechanism responsible for the decision-making process underlying control movements. This author then continues to link speed control and the ability to appreciate and predict a changing complex system to the development of skill, thus making possible the "extracting of constants" allowing smoothness and coordination.

The visual perception of velocity is implicated in the evaluation of the conditions preceding the execution of a driving maneuver; the accuracy of such evaluation determines whether the judgment to execute or refrain from execution is sound. For complex judgment, such as determining the meeting point of two cars on a roadway, Bjorkman (3) has found that the estimate of the meeting point is biased toward the midpoint. The study by Silver and Farber (4) of the passing maneuver indicates that the velocity estimation of the oncoming vehicle is inadequate. Analysis of the perceptual conditions underlying the passing maneuver by Mashhour (5) indicates that the perceptual situation is unfavorable to the human being for the extraction of such information. Brian (6) has examined the visual cues of potential utility in the crossing maneuver.

Both crossing and passing maneuvers involve additive velocities (the speed of the driver's vehicle plus the speed of the other vehicle) that are perceptually modified by the location and orientation of the other vehicle. A simpler perceptual problem investigated by Michaels and Cozan (7), the approach of a stationary roadside object, led

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them to predict that the decision to displace was based on whether the object had a sidewise component of angular velocity (the sidewise component being affected by both forward motion and the object's relative position to the driver). The velocity of the driven vehicle is thus one component common to all driving situations.

The most simple driving situation, once a vehicle is on the road, consists of the driver moving down the road unhampered by other vehicles. To maintain stability and to drive safely requires that traveled velocity be appreciated, for not only is the predicted future state of the system dependent on perceived velocity, but steering is also dependent on it. Poulton (8), treating tracking as an analog of the driving task, considers speed anticipation—the decision aspect based on the perception or inference of the stimulus movement—as essential. Wohl (9) states that the proper steering input is a complex function of vehicle dynamics inversely proportional to the speed or square of the speed depending on the primacy of the visual cue used as reference on the roadway.

Calvert's "streamer theory" (10) indicated that the driver perceives motion from objects in the visual field streaming across the field of view that emanate from a central focus. Gordon and Michaels (11), expanding and mathematically detailing the "streamers," show that the angular velocity of an ideal ground plane is minimal in the fovea and maximum in the periphery. Salvatore (12) has shown in a field study that peripheral visual stimulation results in more effective velocity cuing than frontal visual stimulation under conditions of restricted observation time. The reservation of the peripheral field for velocity sensing and the frontal field for direction cues is attractive but untenable because direction cues other than heading, e.g., lateral placement and path angle, require the peripheral field for their sensing (13).

THE EXPERIMENT

The sensory or perceptual cues to traveled velocity are visual, auditory, kinesthetic, tactile, and vestibular. Because the purpose of the research program was to discover the mechanisms underlying the perception of movement, a field study was conducted earlier that controlled the visual input, eliminated the auditory input, and varied the kinesthetic, tactile, and vestibular inputs by reaching the assigned velocities at two

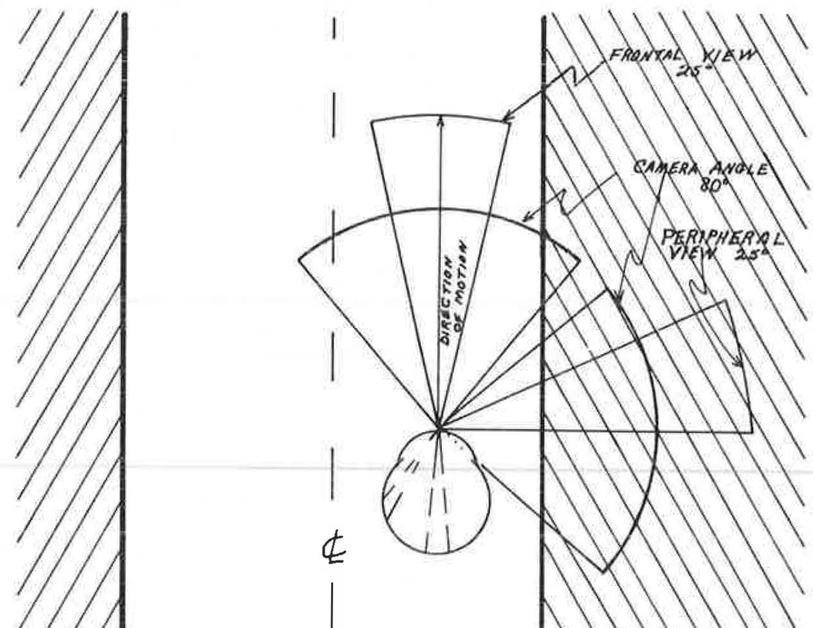
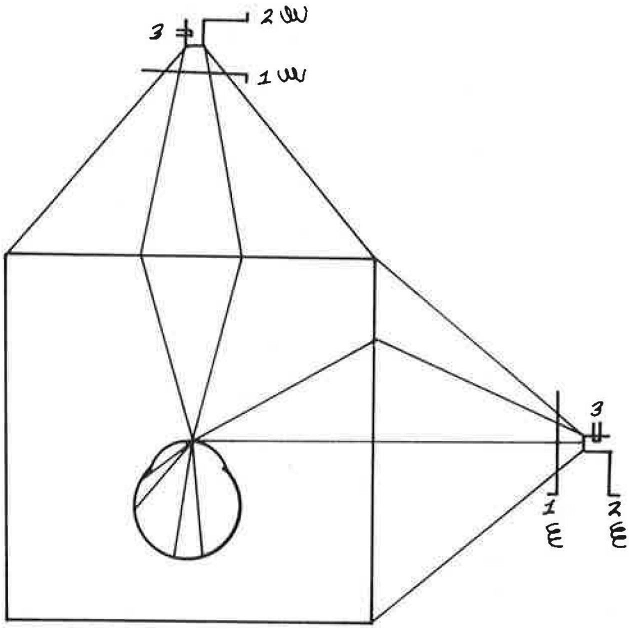


Figure 1. Schematic of the camera arrangement for filming and retinal reception of the projected fields.



LIGHT TIGHT ENCLOSURE

Figure 2. Schematic of laboratory arrangements: (1) solenoid to external shutter; (2) solenoid to projector clutch; and (3) photocell.

levels of acceleration. The purposes of the present laboratory experiment were three: (a) to compare velocity sensing with kinesthetic, tactile, and vestibular cues removed, i.e., zero acceleration; (b) to extend the range of velocities to 100 mph; and (c) to discover the effect of exposure to high velocities on subsequent judgment of the normal range of velocities.

MOVIE TECHNIQUE

A camera was mounted on the front passenger seat of a convertible at normal eye height (48 in.) facing the direction of motion. The convertible was driven to its assigned velocity (20, 40, 60, 80, or 100 mph) at the test site, which was an unopened section of Interstate 70N just outside Baltimore, and the scene was recorded on film. To obtain the peripheral view, the camera was mounted facing the roadside in an orthogonal position in relation to the direction of motion.

For the presentation of the visual input, a light-tight enclosure was built in which the front and one of the side walls consisted of a 4- by 6-ft rear-projection screen. Inside

TABLE 1

EXPERIMENT DESIGN

Experiment	Factor and Extent of Variation	Replications per Cell	Observations per Experiment
1	Mode × 2 Velocity × 3 Subjects × 4	5	120
2	Mode × 2 Velocity × 5 Subjects × 4	5	200
3	Mode × 2 Velocity × 3 Subjects × 4	5	120

the enclosure the subject sat on an adjustable bucket seat to compensate for differential eye height and placed his head in a chin rest in order to locate eye position exactly in relation to the screens. A wooden automobile hood with steering wheel assembly completed the furnishings of the interior. The frontal and peripheral visual fields available to the subject were attained by pasting black-painted cardboard onto the screens.

Two modified Bell and Howell time and study projectors, placed at eye height, carried the spliced film sequence that provided the visual input for the subject. Hoods placed over the projector lamps prevented ambient light spillage onto the rear projection screens. Neutral density filters placed in front of the projector lens reduced the light intensity output of the projectors to an acceptable level. The control of the stimulus and interstimulus interval was arranged by an electronic timing and switching device connected to the modified projectors. The experimenter's console consisted of the electronic device just outside of the light-tight enclosure. The stimulus and interstimulus interval was set prior to each experiment. The frontal or peripheral projector was triggered by a switch. The electronic sequence was as follows: (a) countdown of the interstimulus interval; (b) actuation of the solenoid to the projector clutch, one second prior to exposure, to transport the film at 24 fps (frames per second) at exposure; (c) activation of the solenoid opening the external shutter permitting the image to be projected onto the screen; (d) deactivation of the solenoid closing the external shutter and terminating the stimulus interval; (e) disengagement of the solenoid clutch by the photocell implanted in the lens barrel when the film reaches the black frames; and (f) recycling. Figures 1 through 4 display various aspects of the experimental sequence. Each of the three experiments was considered a three factorial in which each cell was replicated five times. Table 1 indicates the overall experiment design.

The factor "mode" refers to the frontal or peripheral visual field, which was 25 deg in either case. The field of view was centered on the optical axis in the frontal case and was from 90 to 65 deg in the peripheral case. The velocity instances were 20, 40, and 60 mph in Experiments 1 and 3, and 30, 40, 60, 80, and 100 mph in Experiment 2. All three experimental sessions were conducted in the afternoon and including the training and pretesting period occupied between two and three hours. The stimulus interval or presentation time was one second in all cases.

EXPERIMENTAL PROCEDURE

Subjects taken to the laboratory were allowed a few minutes to familiarize themselves with the test environment after which visual acuity, extent of peripheral field, and other visual functions were examined on the Bausch and Lomb Orthorater. Following this, a preliminary explanation of the experiment was given, and the subject was placed in position by the adjustable bucket seat and chin rest. The subject was then shown a training film for both frontal and peripheral fields, in which the vehicle beginning at a standstill accelerated to 60 mph. As the vehicle passed through the 20- and 40-mph level and reached the 60-mph level test velocities, the speed was called out to the subject. This served as the subject's baseline level or anchor. The steady state of 60 mph was maintained for several minutes, and the external shutter was operated manually by the experimenter in order to acquaint the subject with the brief observation time of one second

Following Experiment 1 and prior to Experiment 2, one-second exposures of travel speeds up to 100 mph were given. Prior to experimentation, a random noise generator in the subject's enclosure was switched on at a level sufficient to mask clicks from the solenoids on the projectors. The subject communicated his verbal estimate of traveled velocity by wireless radio to the experimenter sitting at a console adjacent to the subject's booth.

Subjects

The four volunteers, two males and two females, were professionals associated with the Bureau of Public Roads—two highway engineers, a psychologist, and a mathematician. Two subjects wore prescription eyeglasses. Visual acuity was 20/20 or better and the minimum peripheral field 80 deg. The ranges for age and years of driving experience were 23 to 32 and 7 to 14 respectively. The maximum velocity obtained on the

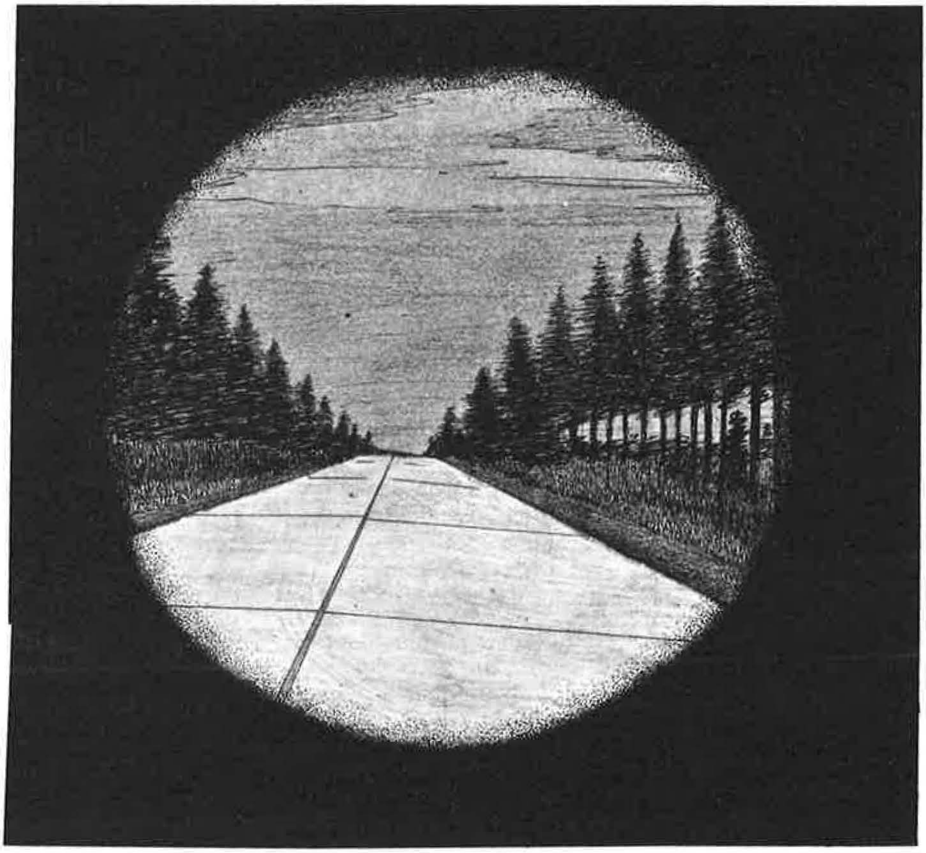


Figure 3. Frontal view seen by the subject.

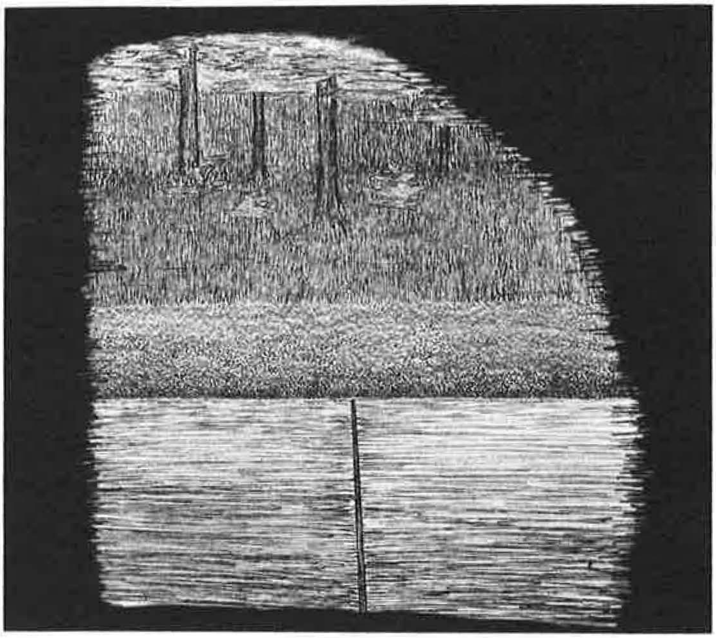


Figure 4. Peripheral view seen by the subject.

TABLE 2

ANALYSIS OF VARIANCE COMPARISON OF FIELD AND LABORATORY METHODS

Acceleration		Laboratory		Field			
		Experiment 1		Experiment 1		Experiment 2	
Source	df[a]	0 mphps		1 mphps		5 mphps	
		MS	F	MS	F	MS	F
Velocity	2	5,948.12	84.97[e]	14,690.23	229.62[e]	11,290.00	386.51[e]
Mode	1	3,000.00	42.85[e]	991.88	15.50[e]	130.21	4.46[c]
Subjects	3	624.99	8.92[e]	42.98	NS[b]	204.75	7.01[d]
V x S	6	163.96	2.34[c]	125.28	NS	148.56	5.08[e]
V x M	2	120.63	NS	47.50	NS	10.33	NS
S x M	3	188.00	NS	140.48	NS	65.28	NS
V x S x M	6	14.95	NS	59.03	NS	49.33	NS
Error	96	70.00		63.96		29.21	

[a]df—degree of freedom.
[b]NS—Not significant.
[c]$p < 0.05$.
[d]$p < 0.01$.
[e]$p < 0.001$.

highway was reported as being between 70 and 115 mph; the approximate yearly mileage, between 7,500 and 25,000 miles.

Instructions to Subjects

The following is the instruction given to the subjects:

"The purpose of this experiment is to find out how people estimate velocity. Your jo in the experiment will be to give verbal estimates of the apparent velocity that the visual stimulation provides to you. Give your estimates to the nearest 5 miles; for example, 25, 30, and 35 mph.

"Your view of the screens (movie) will be intermittent during the experiment. Every 45 seconds you will have a brief view of either the front or side screen. You will not know ahead of time whether your view of the scene or road will be frontal or peripheral so be ready to observe in either direction. The best way to accomplish this is to stare straight ahead, in what we call a stare mode. Try it. Staring straight ahead, you shou be able to view either the frontal or peripheral scene without moving your eyes, as you did in the eye test.

"A tap on the booth from me will be the indication that either the front or the side scene will be available for observation for a short time and you should be ready to ob-

TABLE 3

MEANS AND STANDARD DEVIATIONS COMPARISON OF FIELD AND LABORATORY METHODS

Acceleration Velocity	Laboratory		Field			
	Experiment 1		Experiment 1		Experiment 2	
	0 mphps		0 mphps		5 mphps	
	Frontal	Peripheral	Frontal	Peripheral	Frontal	Peripheral
20 mph						
mean	21.00	29.25	15.00	19.25	14.50	16.25
standard deviation	5.61	8.40	6.00	8.41	4.72	4.97
40 mph						
mean	32.50	46.50	34.25	42.75	31.25	36.00
standard deviation	9.42	10.96	8.05	7.33	8.06	6.05
60 mph						
mean	45.05	53.25	53.25	57.75	48.25	49.50
standard deviation	10.11	9.90	10.54	7.33	8.82	5.68

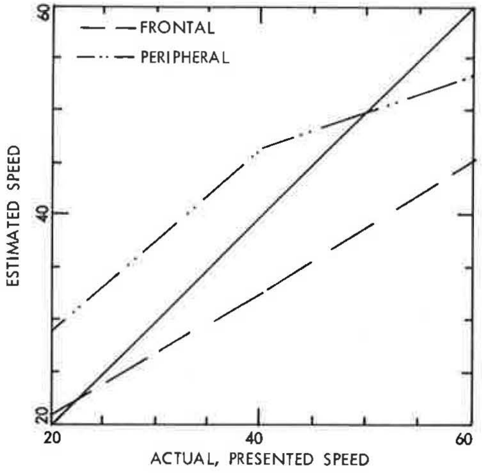


Figure 5. Estimated vs actual speed—laboratory (acceleration, 0 mphps).

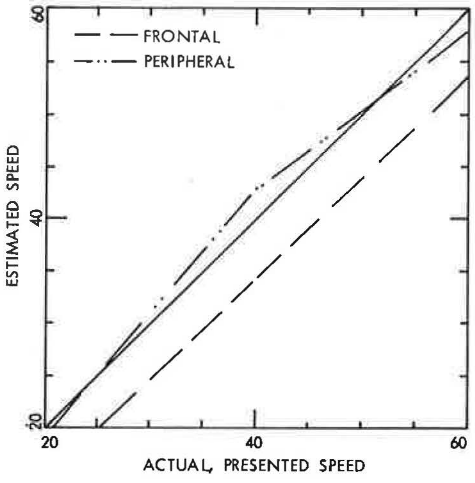


Figure 6. Estimated vs actual speed—field (acceleration, 1 mphps).

serve. As soon as the scene ends, give your estimate immediately. Velocity estimates that are delayed cannot be used. If you are not sure of the speed, guess. Do not hesitate.

"The sequence of events will be (a) dark phase for 45 seconds; (b) tap on booth, be ready to observe; (c) appearance of front or side scene, observe; (d) end of scene, report velocity impression to nearest 5 miles; and (c) repetition of the above until you are fatigued. If you become tired tap on the booth and we will take a break. Are there any questions?

"When I tap on the booth, get ready to observe by staring in front. You will see what is exposed at the side without moving your eyes. Repeat—do not move your eyes. At the outset of the experiment I will ask you to start counting backward, out loud, from 999. Stop counting when you hear the tap on the booth. Resume counting after you have given your estimate."

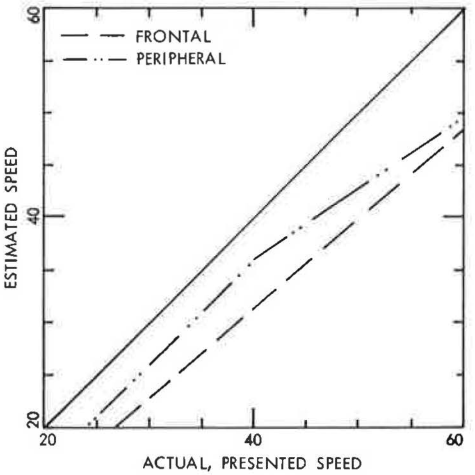


Figure 7. Estimated vs actual speed—field (acceleration, 5 mphps).

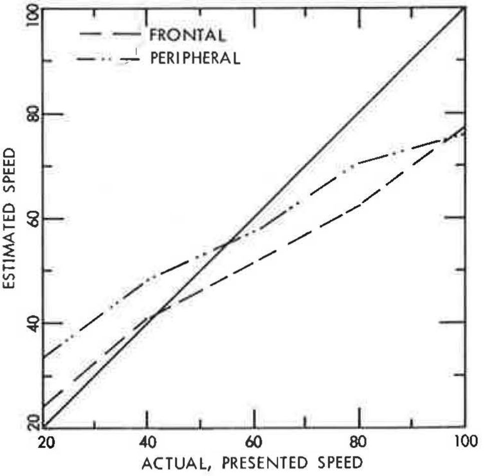


Figure 8. Estimated vs actual speed—laboratory (acceleration, 0 mphps).

TABLE 4

ANALYSIS OF VARIANCE COMPARISON OF LABORATORY EXPERIMENTS

Acceleration		Laboratory Experiment 1		Experiment 2		Experiment 3	
Source	df[a]	0 mphps		0 mphps		0 mphps	
		MS	F	MS	F	MS	F
Velocity	2 (4)[b]	5,948.12	84.97[f]	13,812.18	68.33[f]	4,231.46	19.70[f]
Mode	1	3,000.00	42.85[f]	1,741.00	8.61[e]	421.87	NS[c]
Subjects	3	624.99	8.92[f]	4,857.00	24.03[f]	1,276.87	5.94[f]
V x S	6 (12)	163.96	2.34[d]	277.60	NS	121.46	NS
V x M	2 (4)	120.63	NS	171.94	NS	418.13	NS
S x M	3	188.00	NS	600.66	2.97[d]	627.98	2.92[d]
V x S x M	6 (12)	14.95	NS	270.68	NS	97.23	NS
Error	96 (160)	70.00		202.12		214.79	

[a]df—degrees of freedom.
[b]Numbers in parentheses refer to the degrees of freedom in Experiment 2 where they deviate from Experiments 1 and 3.
[c]NS—Not significant.
[d]$p < 0.05$.
[e]$p < 0.01$.
[f]$p < 0.001$.

Results

The analysis of variance of Table 2 compares Experiment 1 of the present laboratory study with two previous field experiments. For purposes of this analysis, the conditions of the experiment are the same with the exception of the acceleration cues that are removed in the laboratory. The analysis of variance conducted with the movie technique yields a pattern more similar to the field study using a 5-mphps than a 1-mphps acceleration. It appears that too much acceleration and the absence of acceleration have a similar effect. The velocity factor is significant and, in all three analyses but the F-ratio, is smaller in the laboratory, as should be expected. The mode of observation, frontal or peripheral, is more pronounced in the laboratory, which is as expected because the increased acceleration has previously shown to decrease the differential sensitivity.

TABLE 5

MEANS AND STANDARD DEVIATIONS COMPARISON OF LABORATORY EXPERIMENTS

Acceleration Velocity	Laboratory Experiment 1		Experiment 2		Experiment 3	
	0 mphps		0 mphps		0 mph	
	Frontal	Peripheral	Frontal	Peripheral	Frontal	Peripheral
20 mph						
mean	21.00	29.25	24.25	33.75	38.00	28.50
standard deviation	5.61	8.40	10.87	11.60	17.84	7.25
40 mph						
mean	32.50	46.50	40.75	48.25	49.50	44.50
standard deviation	9.42	10.96	11.43	18.04	18.43	14.30
60 mph						
mean	45.05	53.25	51.50	57.25	51.75	55.00
standard deviation	10.11	9.90	18.58	18.26	13.98	15.00
80 mph						
mean			62.50	70.25		
standard deviation			13.08	21.53		
100 mph						
mean			77.00	76.00		
standard deviation			18.80	17.29		

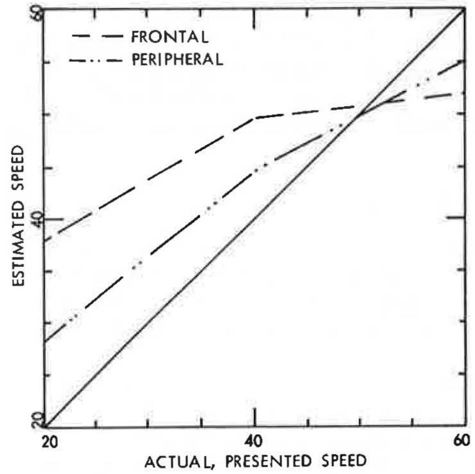


Figure 9. Estimated vs actual speed—laboratory (acceleration, 9 mphps).

The variance source associated with individuals is significant here as it was with the higher acceleration level and it is tentatively suggested that a 1-mphps acceleration level minimizes this source of variance. The velocity-subject interaction follows the same pattern.

The corresponding means and standard deviations are given in Table 3, and the means are plotted in Figures 5, 6, and 7. Comparability was achieved in the laboratory insofar as the peripheral judgments yielded higher estimates than the frontal judgments; the standard deviations are roughly parallel. However, the more accurate results attributed to peripheral estimates of velocity in the field are lacking in the laboratory. Rather, the low velocity (20 mph) is estimated higher and the high velocity (60 mph) is estimated lower; i.e., the estimated range is reduced considerably.

The analysis of variance for Experiment 2, extending the range of velocities to 100 mph, is given in Table 4, the means and standard deviations are given in Table 5, and the means are plotted in Figure 8. Velocity is again significant; mode of observation is significant also but not with as high a level as previously, and the variance attributable to subjects increases. The latter is perhaps understandable because the higher velocities are not commonly experienced. The significant interaction in this experiment is the subjects-mode, indicating that some subjects are no longer responding to the differential stimulation of the frontal-peripheral dichotomy. The peripheral stimulus again yields the higher estimates except at the 100-mph condition. The direct variation of the absolute error with velocity is obvious as can be seen in the flattening of the curve at higher speeds. However, the expected increase of the standard variation with velocity does not materialize.

The results of Experiment 3 given in Table 4 are similar, according to the analysis of variance, to those of Experiment 2 with one major exception. The mode factor is no

TABLE 6

ESTIMATED RANGE AS A FUNCTION OF EXPERIMENT

Experiment	Range Presented	Mean Estimated Range	Percent Estimated/Presented Range
Movie			
1—0 mphps	40	24.03 A[a]	60
	40	24.05 F[b]	60
	40	24.00 P[c]	60
2—0 mphps	80	47.50 A	59
	80	52.75 F	66
	80	42.25 P	53
3—0 mphps	40	20.12 A	50
	40	13.75 F	34
	40	26.50 P	66
Field			
1—1 mphps	40	38.33 A	96
	40	38.25 F	96
	40	38.50 P	96
2—5 mphps	40	33.50 A	84
	40	33.75 F	84
	40	33.25 P	84

[a]A—average. [b]F—frontal. [c]P—peripheral

longer significant and examination of Table 5 and Figure 9 indicates that an actual reversal has occurred at 20 and 40 mph. The frontal stimulus causes velocity estimates to be higher than the peripheral stimulus. The F-ratio for velocity is much smaller than that obtained in Experiment 1. The subjects-mode interaction is significant as in Experiment 2, indicating again that the subjects' response to the differential stimulation is selective at various speeds.

DISCUSSION AND INTERPRETATION OF RESULTS

As the experiment progressed, the effects of velocity became less marked (decrease in F-ratio from Experiment 1 through Experiment 2 to Experiment 3) and the mode factor also became less significant with a tendency toward reversal (frontal estimates higher than peripheral estimates) in Experiment 3. These effects are apparent in Table 6.

The estimated range of Experiment 1 is 60 percent of the actual range, compared with a range of 96 percent and 84 percent with the field tests. This reduced range in the laboratory is in agreement with the findings of previous investigators (14, 15). These results may be explained by the fact that moving the experiment to the laboratory has eliminated the accelerative or force-sense feedback mechanism active in the field (16). It does not, however, square off against the contention that the visual system is most sensitive to motion because the movement of the visual field is directly proportional to vehicular velocity (11), whereas the force senses—kinesthesis, vestibule, and somesthesis—are not so finely graded. Of course, the auditory cue was also missing and an experiment is now being conducted to determine the influence of the auditory cue on velocity sensing.

The reduction in range as the experiments progressed and the reversal in the estimated range in the frontal and peripheral fields needs explanation. The reduction in range indicates that the ability to discriminate velocity visually has been compromised, possibly because of fatigue and monotonous environment. In addition, the subjects were in a completely dark field between stimuli and it is possible that as the experiment progressed and fatigue entered the picture, a beta effect—apparent movement caused by an increase of illumination of part of the field—was produced. This is a good possibility because the beta effect would be expected to be more pronounced in the frontal field (Table 4 indicates that frontal estimates were higher at the end of the experiment). The discrepancy of the estimated range of the frontal and peripheral fields can be explained in the same fashion. That is, the judgment of the frontal field is more influenced by the beta effect than by the angular velocity of the visual field.

The subjects' comments concerning the efficacy of modal stimulation are of interest at this point. "Estimating speed from the periphery is a farce." All comments showed agreement in deprecation of the periphery. However, the previous field experiments show the periphery to produce greater reliability and accuracy, and the present experiments indicate greater resistance of the periphery to experimental artifacts. It is speculated that the frontal field is overevaluated in the sense that the same angular subtense, 25 deg in this particular case, includes a much greater expanse of real territory. Also, normal fixation is in the frontal-parallel plane. A real basis for the unfavorable comments pertinent to the periphery may be that smaller apparent aperture of the periphery resulted in blocking off desirable motion cues at the higher speeds. That is, the degree of acceptable blur may be a constant and the estimate of traveled velocity is obtained by locating its position further forward in the periphery, a result that would explain the flattening of the curve at the higher speeds. Further, the peripheral movement cues may be traded more easily for the directional cues of the frontal field (a move that may or may not be wise).

Past studies of velocity sensing summarize results in terms of over- and under-estimation. Suhr (17), in comparing velocity sensing on the road and with a laboratory device, states that there is under-estimation of lower velocities and over-estimation of higher velocities. Suhr's graphs indicate a reduction of the estimated range in the laboratory. Chubb and Ernst (18) studied velocity attainment on real highways of varying traffic densities and reported that lower velocities were over-estimated and higher

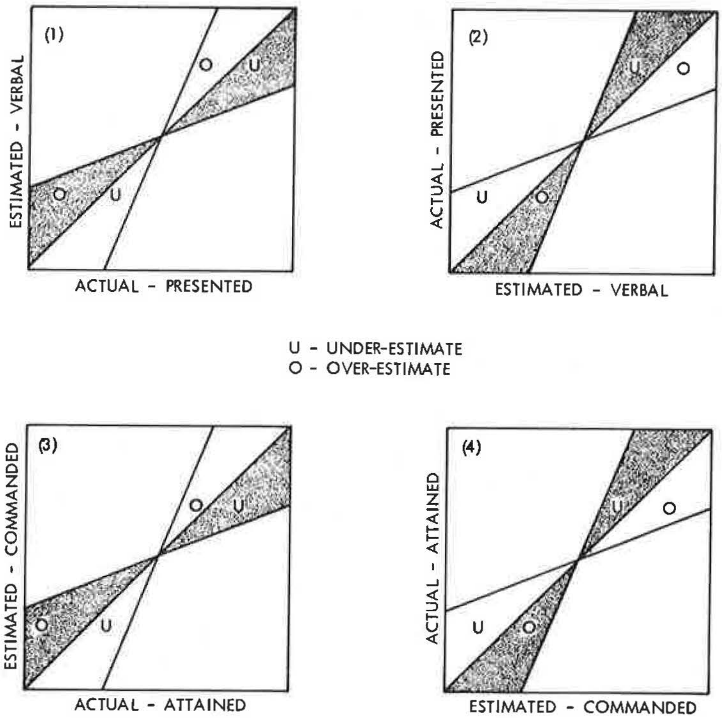


Figure 10. Over- and under-estimation as a function of the label on the coordinate system.

velocities were under-estimated, with the higher traffic density increasing the estimates uniformly. Snider (19) compared the methods of velocity production and velocity estimation and stated over-estimation or production of lower velocities and under-estimation or production of higher velocities. It appears that a body of knowledge is being accumulated in this area. However, interpretation is in doubt because of a confusion, first pointed out by Hakkenen (15), of what constitutes over- or under-estimation. The confusion appears to be methodological and results in discrepancies as to what is plotted on the coordinate system. The various possibilities that may be plotted when the methods of velocity production and velocity estimation are used are shown in Figure 10. It can be seen that what is termed over- or under-estimation will depend on what is plotted on the x-axis and the y-axis, and inversion of the two will reverse the type of estimate used to describe the results. Our contention is that graphs 1 and 3 will yield the correct description. Often in the production procedure, the command or instructed velocity rather than the actual or produced velocity is placed on the x-axis (a procedure probably resulting from the fact that the dependent variable is usually measured after the independent variable). Hakkenen also reported over-estimation of low speeds and under-estimation of high speeds with the tendency of the movie technique to emphasize the distortion of the true speeds. Our own results follow this pattern, and it was hypothesized that the restriction of the visual stimulus to the frontal field in the laboratory because of the technique caused the restricted range. However, the addition of limited peripheral streamers in this experiment did not result in an increased range.

A succinct manner of describing the relationship of the subjective sensation of velocity to the objective stimulus is to give the plotted slope. This relationship for various sources of stimulation has been defined by Stevens as following a power law (20). The sensory input influences the exponent. For example, Ekman and Dahlback (21) find an exponent close to two for the velocity estimation of targets (similar to the target of the oncoming or crossing car), and Pellegrini and Ponzo (22) report that traveled velocity tends to be under-estimated following deceleration and over-estimated following acceleration. Kobayashi and Matsunaga (23) noted that the rate of filming and reproducing the simulation affects the slope. Denton (24) concludes that, in a driving situation in which the production methodology was utilized, sensation is not a simple power function of speed. Senders et al (25), in a test track situation have shown that the actual velocity tolerated (or produced) decreases with the amount of time available for observing the road.

CONCLUSION

The series of experiments reported in this paper was directed toward the explanation of the effect of sensory input on the sensation of traveled velocity. The interaction between speed and guidance cues in frontal and peripheral fields is left for future study. More immediate effort will be brought to bear on documenting the addition of the auditory cue and the variation of observation time on judgment and performance.

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Appendix

SUBJECTS' ORTHORATER VISUAL FUNCTIONS SCORES AND MAXIMUM VELOCITY REPORTED ATTAINED ON THE HIGHWAY

Item	Subject			
	L.S.	G.L.	E.H.	P.M.
Prescription eyeglasses	None	Far vision	Far vision right eye Near vision left eye	None
Far vision—phoria				
Vertical	5	6	9	5
Lateral	7	6	7	11
Far vision—acuity				
Both eyes	10	12	12	10
Right eye	10	12	10	10
Left eye	9	10	10	11
Near vision—phoria				
Vertical	3	3	8	2
Lateral	7	4	11	9
Near vision—acuity				
Both eyes	11	12	12	12
Right eye	11	11	11	12
Left eye	11	11	12	12
Periphery				
Right in-out	80°-95°	85°-85°	95°-90°	85°-90°
Left in-out	85°-90°	80°-85°	100°-95°	95°-95°
Maximum velocity	70 mph	70 mph	115 mph	110 mph