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DRIVER RESPONSE TO ACTIVE ADVANCE WARNING SIGNS AT HIGH-SPEED SIGNALIZED INTERSECTIONS

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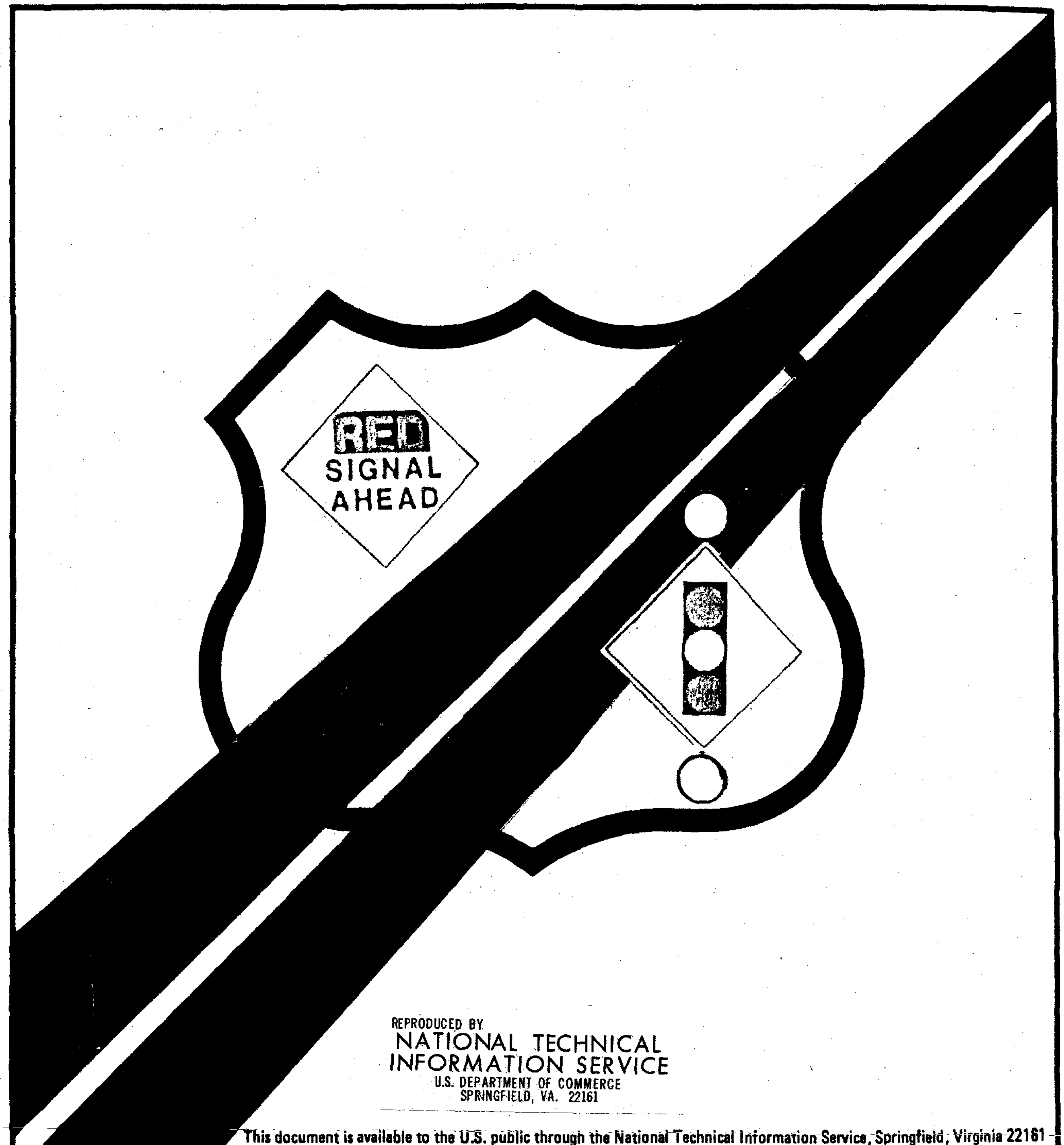

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16. Abstract

This research was conducted on the FHWA highway driving simulator (HYSIM) using 60 test subjects to examine driver responses to active advanced warning systems (AAWS) at high-speed signalized intersections. Measures of effectiveness included identification distance, reaction time, vehicle approach speed, and vehicle lateral placement measured on the HYSIM. Driver preferences were obtained from an interview following the driving test.

The AAWS's examined were "PREPARE TO STOP WHEN FLASHING" with flashing beacons using both a diamond-shape sign, and a rectangular sign mounted both on an overhead structure and ground-mounted on the roadside. Also a symbolic signal ahead sign with flashing lights and a "RED SIGNAL AHEAD" sign with the "RED" flashing, were candidate test signs. The standard "SIGNAL AHEAD" and the symbolic signal ahead signs were also displayed.

The results indicated the symbolic signal ahead sign with flashing beacons had the greatest identification distance among all the test signs and was preferred by most drivers. No differences could be detected between ground-mounted versus overhead signs. All the active advance warning signs were superior to the standard passive warning signs.

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ABSTRACT

This laboratory study was conducted, on the FHWA Highway Driving Simulator, to draw inferences about driver response to and preferences in six Active Advance Warning Signs (AAWSA) at High-Speed signalized intersections. The AAWS examined in this study are as follows: (1) PREPARE TO STOP WHEN FLASHING sign (diamond, ground-mounted), (2) PREPARE TO STOP WHEN FLASHING sign (diamond, overhead), (3) PREPARE TO STOP WHEN FLASHING sign (rectangular, overhead), (5) flashing "RED" SIGNAL AHEAD sign, and (6) flashing Symbolic Signal Ahead sign. The AAWS were studied at two different locations: (1) intersections hidden by horizontal curves, and (2) unexpected intersections at rural expressways.

The objectives of this study were to run simulated driving sessions, with 60 test subjects, on the FHWA Highway Driving Simulator to: (1) examine driver responses to and preferences in AAWS, (2) examine the effect of sign message length on driver reaction to the signs message length on driver reaction to the signs and (3) determine the most effective position of the warning sign, i.e., overhead or ground mounted. Measures of effectiveness consisted of two types: objective and subjective data. Objective data included identification distance, reaction time, vehicle approach speed, and vehicle lateral placement. Subjective data consisted of driver preference on AAWS questionnaire.

The flashing Symbolic Signal Ahead (FSSA) sign was shown to be significantly the best with a granter identification distance than all other tested signs.

Contrasting between the FSSA sign and the MUTCH conventional warning signs for high-speed signalized intersections, i.e., the passive SIGNAL AHEAD <u>or</u> the passive Symbolic Signal Ahead sign, revealed that the FSSA sign is significantly better than the MUTCD conventional warning signs, for almost every objective variable collected on the simulator.

Drivers' first preference was overwhelmingly for the FSSA sign. The PREPARE TO STOP WHEN FLASHING signs wee the least preferred signs by subject drivers.

Differences in driver responses to ground-mounted signs versus the overhead sign were not statistically significant.

Notice

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INTRODUCTION

Background

Introduction of signalization on high-speed highways creates the potential for a significant increase in traffic accidents. The most pressing problem at high-speed signalized intersections is the creation of a decision zone, where a driver may correctly decide either to stop or to proceed through an intersection. The problem occurs when the driver of a leading vehicle decides to stop but the driver of a following vehicle, also within the decision zone, decides to proceed through then intersection. An abrupt stop could result in a rear-end collision. A driver not having reached the decision zone and deciding to go through the intersection could produce a right-angle collision.

A variety of countermeasures have been proposed and implemented to address this problem. Yellow time adjustment, which is the least expensive and most common signal timing countermeasure, has been used at many high-speed intersections. However, it is apparent that yellow time adjustment cannot provide efficient decision zone protection due to the wide variation in driver behavior and variation in vehicle approach speeds. Another "conventional" countermeasure is detector placement. Although advance detection configurations can provide a significant reduction in decision zone accidents, this countermeasure modifies the signal controller's action based on driver behavior. However, it is evident that the information to modify drivers' behavior (which is the preferred solution to the problem) should not be limited to warning the driver of the existence of a signal but should vary according to the indiction shown or existence of a signal but should vary according to the indication shown or about to be shown o the signal. Active (or dynamic) advance warning signs are traffic control devices, placed at or in advance of high-speed signalized intersections, which provide information to drivers on whether they should stop or proceed.

Active advance warning signs came into general use in the late 1960's and early 1970's. Several states installed flashing RED SIGNAL AHEAD signs patterned after those used in New Jersey, which apparently was the first State to use such devices. Other agencies, who were not aware of what others were dont, developed their own similar dynamic devices. Most states apparently installed a particular type of sign and, begin satisfied with it, have continued to use the sign. A few states tried several messages until they found one that they believed was effective. This accounts for the wide variety of active advance devices function. Ozanne surveyed 25 city and state traffic engineers across the United States about their use of active advance warning signs. (1) Ozanne found that not all signs are activated at the same time. also, it was noted that installation of advance warning signs seemed to reduce driver confusion and difficulties at unexpected intersections. Active advance warning signs were reported was an effective solution in reducing rear-end accidents.

More recently, a nationwide survey of practicing traffic engineers was conducted to gather data on the types of accident problems and to assess various countermeasures at high-speed signalized intersections. (2) Eck and

Sabra reported that hidden intersections and rural expressways where signs are unexpected are the two main circumstances creating problems at high-speed signalized intersections. At such locations, rear-end accidents are the most pressing problem, followed by right-angle accidents and red violations.

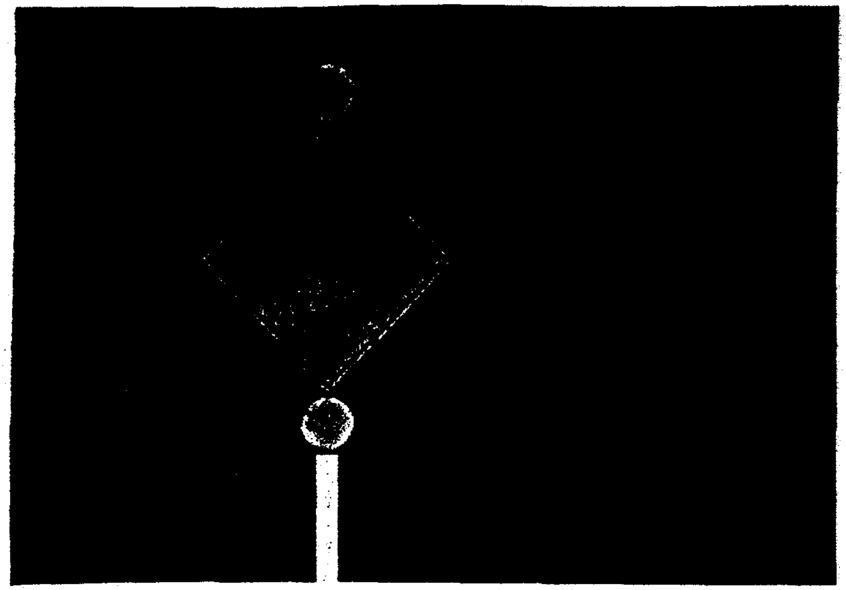
There are a variety of active advance warning signs in use around the country. Virtually all can be grouped into one category: flashing RED SIGNAL AHEAD signs. Essentially, the flashing RED SIGNAL AHEAD signs consist of a sign panel with word or symbol message and yellow (or other) flashers that illuminate a predetermined time before the start of red. In most cases, an auxiliary logic package activates the flashing light before the termination of the green interval. figure 1 shows typical sign messages and configurations for the flashing RED SIGNAL AHEAD signs. All signs are placed well in advance of the flashing RED SIGNAL AHEAD signs. All signs are placed well in advance of the intersection where they can be clearly seen by approaching drivers. In arrangements (a), (b), (c), and (d), the yellow flashers, attached to two corners of the sign panel, are activated and start flashing a predetermined time before the end of the green interval. Note that some of these signs are ground-mounted while others are overhead-mounted. There currently are no general guidelines for the location of active advance warning signs, although overhead signs cost significantly more than ground-mounted signs.

The device shown in Figure 1(e) operates in a manner similar to the devices just presented. However, the arrangement includes a signal head symbols on the sign panel at all times with the yellow flashers activated at a predetermined time before the end of the green interval.

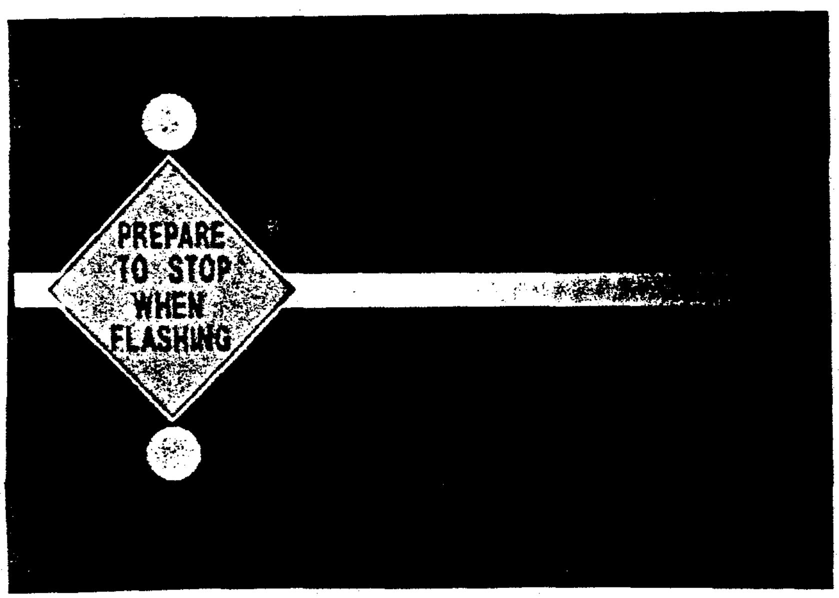
Arrangement (f) in Figure 1, which is a true flashing RED SIGNAL AHEAD sign, operates in a different manner than the other signs. This neon-lighted sign displays only tow messages--"RED SIGNAL AHEAD" (RSA) or "SIGNAL AHEAD" (SA). The RSA message is activated preferably near the end of the green interval of message is displayed at all other times during the cycle. The first message operates with the word "RED" flashing alternately with the words "SIGNAL AHEAD." The second message operates with only the words"SIGNAL AHEAD" not flashing.

Problem Statement

In spite of the availability of the solutions just presented, accidents at high-speed signalized intersections continue to be a persistent problem nationwide. An indication of this was provided by a recent survey of research needs by the Transportation Research Board Committee on Traffic Control Devices. The subject of advance signing to improve safety on high-speed signalized approaches ranked fifth in overall priority in terms of research needs. While active devices have been shown to be effective at certain locations, there are no general warrants or guidelines for their use at high-speed signalized intersections. The Manual on Uniform Traffic Control Devices (MUTCD) does not include any application standard to define the use, design, installation, or timing of active warning signs. (3) State and local highway agencies are continuing to modify this type of signing in attempts to improve the effectiveness. However, these studies are generally of a trial-and-error nature and usually lack a sound human factors basis.

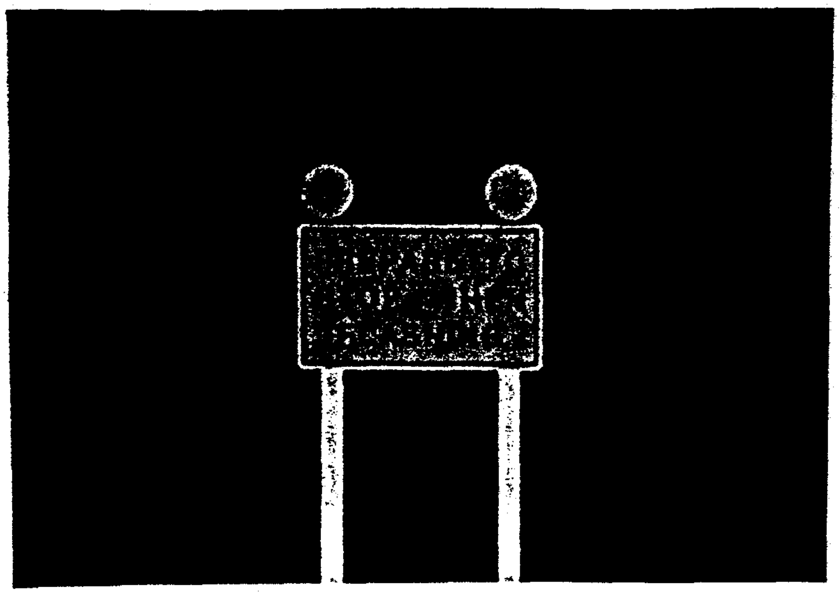


(a)

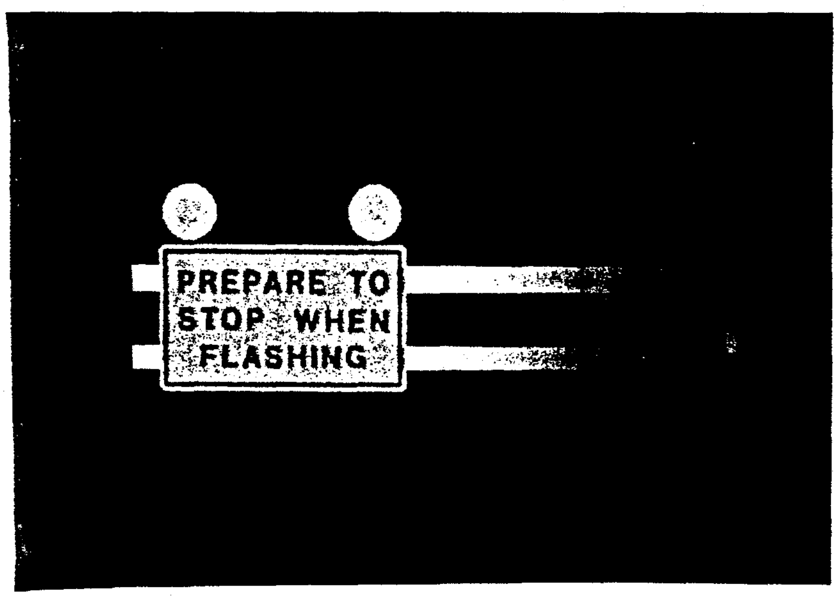


(b)

Figure 1. Messages and Configurations for the Flashing Red Signal Ahead Signs

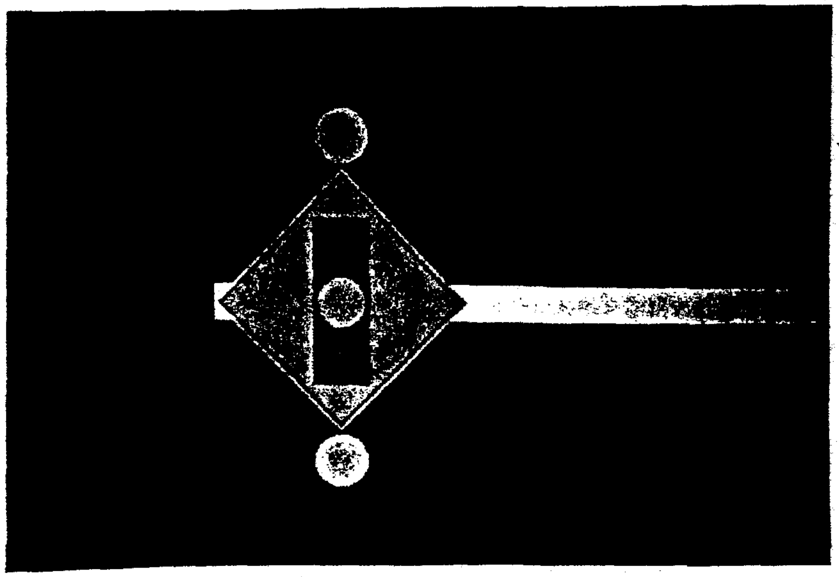


(c)

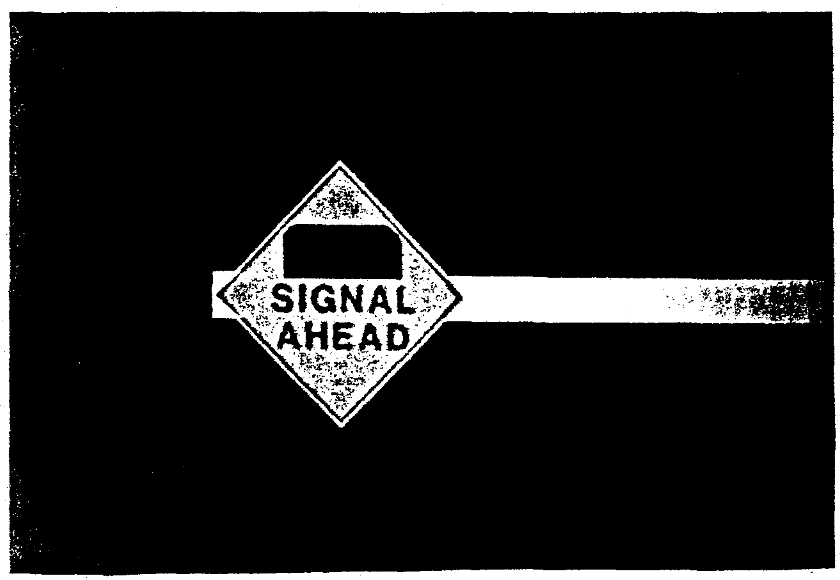


(d)

Figure 1 (cont'd.)



(e)



(f)

Figure 1 (cont'd.)

An important factor associated with active devices is their initial cost. Installation cost range from $200 to $6,000 per intersection approach depending on the device used and its location. (2) It is apparent that use of these devices where they are to needed or effective could lead to unnecessary expenditure of funds which might be used in other areas of highway safety. Therefore, further investigation into developing warrants for active advance warning signs is needed. Field studies are needed to investigate the influence of variables such as traffic volume, approach seed, approach geometry, and land use on the effectiveness of active warning devices. Small sample sizes and a limited range of traffic and environmental variables have precluded drawing conclusions from the studies done to date.

To evaluate countermeasures fully, the field work should be supplemented by laboratory investigation, using a driving simulator, of the human factors aspects of the problem. In this way, the effectiveness of the countermeasures in terms of driver comprehension could be assessed. The driving simulator would also provide an opportunity to determine the best wording and/or symbols for use of the dynamic devices. Due to these difficulties associated with field measurement of driver response, it has become very practical to use driving of detailed driver response data in a short period of time. A simulator also permits one to experiment with many locations and sign/signal types in a short period of time. Thus, use of a driving simulator appears to be the best approach to gathering the information needed to address the questions raised above.

Objectives of the Study

The research effort described here involved a laboratory study (using a driving simulator) to investigate driver response to active advance warning signs at high-speed signalized intersections. Specific objectives of the study were as follows:

- To develop on the simulator, using the Scenario Definition Language (SDL), a roadway network and intersection approach geometry of appropriate complexity and detail in terms of common real-world parameters such as horizontal alignment, width, delineation, traffic control devices, and roadside objects. The simulated roadway will be a computer-generated calligraphic line drawing projected by a video camera/large-screen TV raster scan system.

- To locate subjects for the experiment; to determine their sex, age, and availability; and to screen them to establish that they have no serious visual or other physical problems that would affect their ability to take part in the experiment.

- To run simulated driving sessions, with the test subjects, on the FHWA Highway Driving Simulator to: (1) examine driver responses to and preferences in six active advance warning signs; (2) examine the effect of sign message length on driver reaction to the signs; and (3) determine the most effective position of the warning sign, i.e., overhead or ground-mounted.

Measures of effectiveness were recorded on the simulator in terms of the following parameters: identification distance, reaction time, vehicle approach speed, and vehicle lateral placement. Additional driver inputs were gathered using a questionnaire.

Organization of the Report

This report consists of our sections. Section I is an introduction to the problem and statement of research objectives. Section II describes the methodology of the experiment. Procedures for collecting driver response data, i.e., identification distance, reaction time, vehicle approach speed, and vehicle lateral placement, are outlined in Section II.

Section III presents a quantitative and qualitative analysis of the data. The results of the analysis, that is, the conclusions and recommendations for future research are presented in Section IV.

SECTION II

METHODOLOGY OF THE EXPERIMENT

This chapter describes the simulation methodology and procedures used to collect performance dta on the Federal Highway Administration (FHWA) Highway Driving Simulator. Since the FHWA Highway Driving Simulator was used as a major part of this experiment, this chapter introduces the Driving Simulator by describing its advanced technology and primary features. Also, methods of sign and roadway features simulation are explained in detail in this chapter. Definitions and data collection methodology for the measures of effectiveness used in this study (identification distance, reacation time, vehicle approach speed, and vehicle lateral placement) are illustrated. Development of the subject questionnaire on active advance warning signs is described. Finally, subject selection procedures (selection, training, and testing) are summarized.

The FHWA Highway Driving Simulator

Overview--The FHWA Highway Driving simulator developed by Systems Technology, Inc. (STI). Its functional capabilities are summarized in Figure 2. (4) Primary features of the HYSIM Include the following:

- A realistic in-car environment (car cab) that includes all the basic controls and displays trough which the driver interacts with the environment; e.g. steering wheel, brake pedal, accelerator, rear- and side-view mirrors, and the standard complement of secondary controls/display found in the 1980 Ford Fairmont sedan body which was used intact.

- Full-size large field of view (50 degrees lateral x 40 degrees vertical) which provides the driver with a perspective representation of key roadway-defining elements--e.g., road edge and lane lines--which change in synchronous response to driver inputs.

- Full speed-range vehicle dynamics including representation of engine rpm and brake responses and two-degree-of-freedom (slideslip and yaw rate) lateral/directional equations of motion.

- Projection of pre-selected (color, detail), high-resolution slide images, e.g., signs--in registry with the oncoming roadway.

- Provision of autiory cues common to the car/highway environment; e.g., engine whine, roadnoise, siren, crash, tire thump (e.g., Bott's dots).

- Measurement and collection of performance data; e.g., lane deviation, control application.

- Centralized simulator control including initiation and termination of experimental run, CCTV monitoring of simulator status and driver performance, and two-way voice communications with the driver.

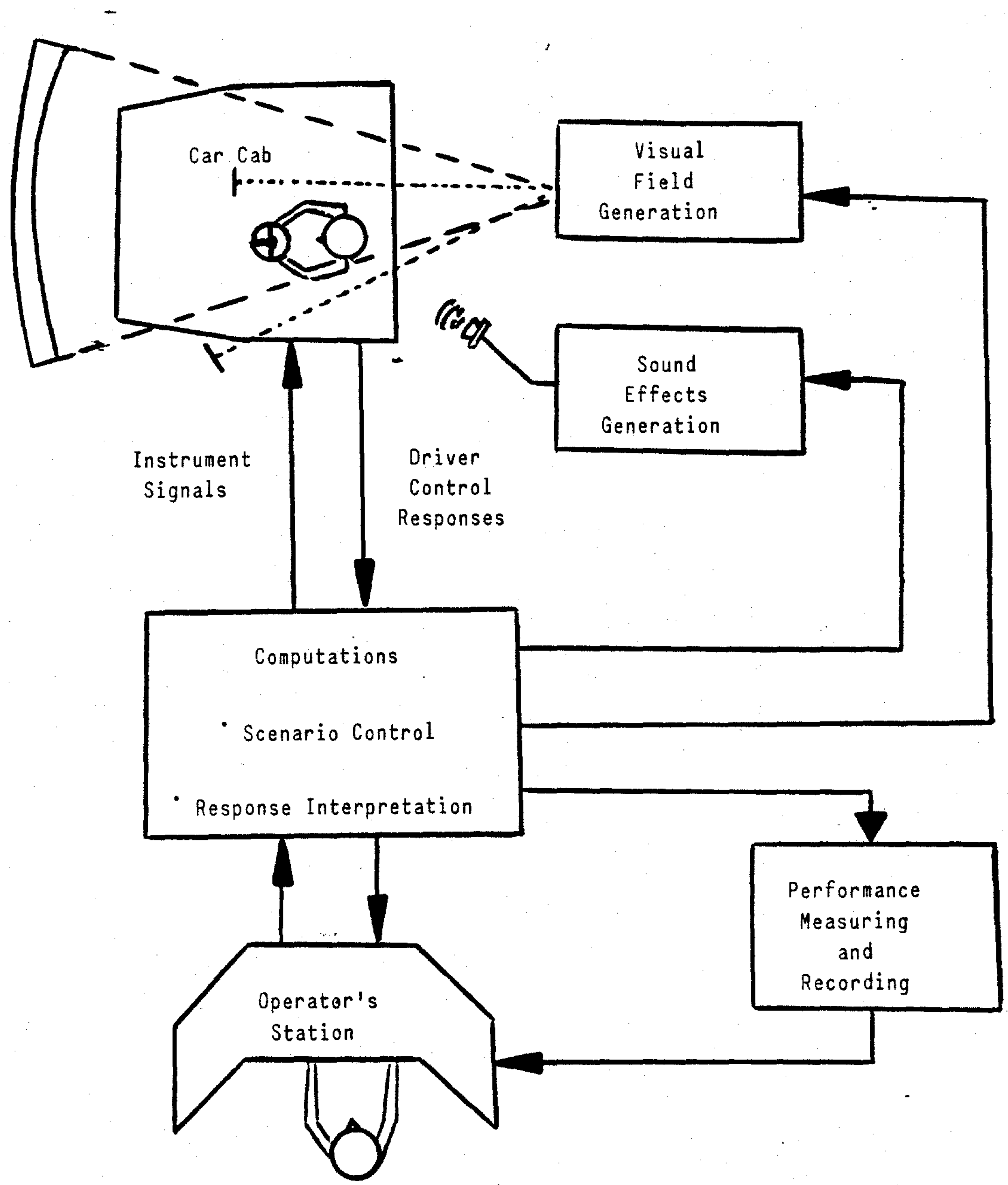


Figure 2. Simplified Functional Diagram of the Federal Highway Administration's Highway Driving Simulator. (4)

Roadways generated by the HYSIM are computer-generated calligraphic line drawings projected by a video camera/large-screen TV RASTER scan system. Colors and forms of the roadway elements (i.e., geometric features) represented are user-definable. The HYSIM has the capability of generating several roadway elements in addition to creating a roadway network of arbitrary complexity and details in terms of common real-world parameters such as horizontal alignment, width, delineation, alternative routes, and roadside objects. The HYSIM Provides a simple and direct means of locating objects and events along the road; e.g., sign and speed zone enforcement.

The presentation of high-resolution, color-rich, and detailed images, such as signs, is the function of the system's four sign projectors. Each sign projector consists of an 80-slide random access projector and zoom lens. Images are projected into a mirror which is pivoted to provide horizontal image movement on the screen. Slide image registry with road is provided by computer-controlled servos which rotate the mirror to position the image laterally on he screen and increase the zoom ratio to enlarge the image as the sign is approached by drivers. Servos on the zoom lens aperture and in the lamp voltage drive provide the computer with a means of maintaining sign brightness with increasing zoom ration, as well as a varying brightness to simulate difference ambient visual conditions and fading the sign on and off.

The software delivered with the HYSIM is treated as part of any experiment conducted on the driving simulator. The software is utilized as an interactive tool that assist as in programming, debugging, and loading the Scenario Definition Language (SDL) programs. In addition, the software is used to complete the picture-displaying task, as well as recording and collecting driver performance data. This discussion will present both the software used to perform the experiment described her and the modifications nd/or additions to the software delivered with the HYSIM. the functions thus provide include the following:

- o Special-purpose data collection and sign extinction triggered by a driver's sign identification response (i.e., clicking the headlight dimmer switch).
- o Computer I/O to cue the operator that a sign was about to appear and to request and accept his (coded) description of the subject's response to a sign.
- o Post-run data processing to combine collected performance and response data and format it for later analysis and to compute and summarize a reward/penalty payoff used to simulate real-world motivation.
- o Modified slide projectors with high-intensity lamps. The modifications of the slide projectors provide proper flashing operation of the active advance warning signs; over-driving the lamps to higher voltage allows full sign brightness.

Capabilities and Limitations--The FHWA Highway Driving Simulator is currently being used in highway and traffic safety research and provides the following advantages:

- opportunity to experiment without danger to life and property as might be the case in real-life situtation;
- ability to establish and maintain the experimental controls necessary for valid results;
- use in predicting the effect of propósed designs as control measures;
- opportunity to measure scientifically, with laboratory instrumentation driver performance in specific situations;
- economical for research studies;
- used as a screening device in research and also used as a training device and for preliminary design purposes for traffic control devices.

The most important aspect of the FHWA HYSIM is capability of studying research variables in a systematic fashion and thus determining their effects on driving behavior. For example, on the FHWA HYSIM it is possible to change road configuration, reduce potential cues, alter steering-force gradient, or introduce a talkative passenger, and simultaneously observe the effects of these variables on the driver performance. These variables--the road, the vehicle, and the social situation--can be manipulated either as single elements or as a pattern.

Although the FHWA HYSIM is considered to be the most advanced driving highway simulator in the United States, it still suffers some major drawbacks. These major drawbacks are as follows:

- Needs extensive experience in handling the technical operation, as well s the manpower to sufficiently handle the programming task.
- The driver does not have a total 360 degree field of view. The FHWA HYSIM Offers only 50 degree lateral view and a 40 degree vertical view providing a two-dimensional system.
- this limited peripheral vision means that subjects, especially elederly ones, are susceptible to motion sickness.
- The FHWA HYSIM cost slightly over $1 million to develop and build.
- The HYSIM cannot yet simulate vertical change in grade elevation; therefore, it only simulates flat roadways with typical horizontal curvature.
- The system is a fixed-base system; therefore, it limits the degree of freedom the driver can encounter in real-world driving conditions.
- The FHWA driving simulator cannot generate or simulate other traffic on the roadway.

It appears that the HYSIM can offer many advantages to researchers, but in most cases researchers need to be sensitive to validating research studies conducted on the HYSIM due to the fact that such experiments suffer from some major limitations, as explained above. Note that several of these major drawbacks can be addressed by investing more capital to upgrade the HYSIM.

As a matter of fact, this study has added to the development of the HYSIM since more hardware devices were installed to make the flashing lights operator properly. The addition of these hardware devices will help in future research on the HYSIM to examine traffic operational aspects similar to the ones in this study; for example, flashing devices at rail-highway grade crossings or flashing lights at construction work zone sites.

Adapting the Simulator to the Study

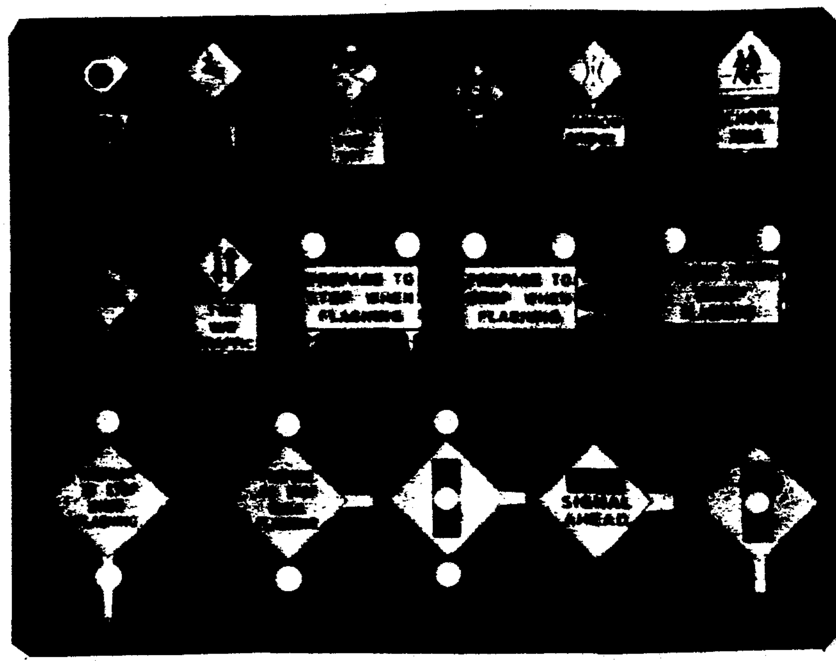
As was stated earlier in the objectives, the FHWA HYSIM had to be adapted for this laboratory research study. Two main tasks had to be completed to generate and display signs and roadway features; (1) sign features task and (2) roadway features task. EAch of the two tasks will be discussed in the following sections. Two systems utilized to complete this research study should be noted however: The Tech Graphics II system and the HYSIM system. The Tech Graphics II system was used to generate all highway signs and signals; the HYSIM system was utilized to generate and display the test roadway and traffic control devices.

Sign Features--The first step in the definition of the driving scenario was the selection of the "other" signs to be shown in addition to the eight advance warning signs of primary interest. Consideration was given to the following factors in selecting signs:

- o Representation of each of the MUTCD categories; i.e., regulatory, warning, and guide signs. The wide variety of signs used in this experiment is shown in Figure 3.
- o The signs represent as wide a variety as possible in form, color, and message content.
- o The simulation be made as realistic and diverse as possible to enhance carryover of real-world driving habits and maintain subject interest.

Active signs, as well as passable signal ahead signs, were presented sequentially as an integral part of a continuous roadway. Active warning signs were placed immediately after standard regulatory, warning, or guide signs. Speed limit signs were used to indicate speed zones. A total of six active warning signs were presented, as well as to passive signal ahead signs (symbolic and word message).

Projected sign image sizes were set to simulate the apparent size of real-world signs as recommended by the Standard Highway Signs manual. (5) The practical range (distances where the zoom lens begins to zoom on projected signs) of the sign projector zoom lens is about (:1, and the maximum size approach distance (distance from the vehicle where projected signs appear in



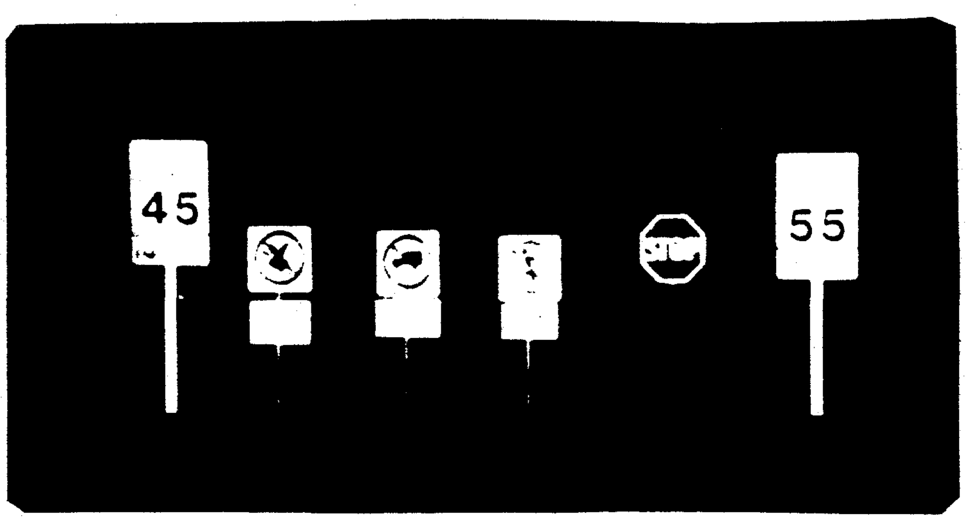


Figure 3. Summary of Roadway Signs Used on the HYSIM.

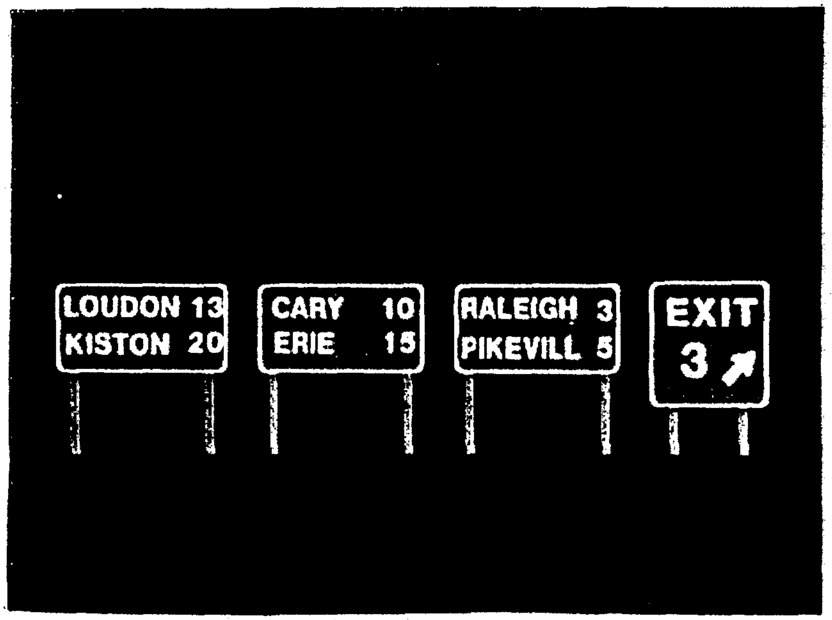


Figure 3. (Continued)

their maximum sizes) for the signs was set at 50 ft. This represents a minimum practical range for sign recognition. At closer distances, signs move vary rapidly in the dispaly periphery at reasonable driving speeds; this limits driver capability to recognize signs. Thus, based on the practical range of the sign projector zoom lens, the range over which signs changed size was 450-50 ft. The sign controller was first activated at an equivalent approach distance of 600 ft. For the first 150 ft (i.e., 600-450 ft) the brightness of the sign was gradually increased in order to avoid having the sign "pop" on. During the last 50 ft of approach, the mirror servo moved the sign into the display periphery to simulate real-world conditions, without any further change in sign size.

The visual range distance, 600 ft, for each active warning sign presentation required a minimum distance of 800 ft between signs. The additional 200 ft was needed to provide time for selection of the next slide-sign.

In most conditions, active advance warning signs (AAWS) were flashing when the drivers could first see them; they remained flashing until drivers passed the sign. Flashing rate (60 flashes per minute) on the AAWS was controlled y an internal lamp circuit which overdrove the projector lamps to obtain the brightness quality found in real-world flashing beacons. Other dummy flashing signs were seen along the roadway and they were similar to those tested. AAWS were located approximately 800 ft in advance of intersections hidden by horizontal curves and 1200 ft in advance of intersections at rural expressways.

Slides of sign images that were used on the HYSIM were made on the FHWA Tech Graphics II system. The Tech Graphics II consists of an IBM PC computer; memory expansion card; red, green, and blue (RGB) menu monitor and interface card; intelligent graphics terminal (IGT): RGB high resolution monitor; garphics tablet and pen; 20-megabyte disk drive; and a digitizer. Resolution of the graphics system is a format of 1024 x 780 pixels. The IGT uses graphics terminals for display of high quality graphics produced by the system. The IGT actually consists of two parts: the IGT monitor and the IGT frame buffer. The graphics system generates 16.7 million possible colors by mixing different levels of red, green, and blue on the IGT monitor; however, only 256 different colors can be displayed at one time. The hard disk, which is the main device for the Tech Graphics II system, can contain five million bytes. The memory on the hard disk is permanent; that is, when the computer is turned off, the contents of the memory are retained.

Several programs were utilized to create drawings of sign images. These programs are interactive and user-friendly. Some of the programs used to draw the signs for this experiment are as follows: Paint, Typewriter, Reduce, Shade, Blockmove, Edition, Loadpic, Shade, and Filer, among others. After a sign was created, a RGB camera was used to take slides of the sign. The RGB camera can photographically record any of the graphics created with the Tech Graphics II system. In order to create high precision photographics, the camera uses a black and white monitor to display the red, green, and blue tonal levels of the IGT image. The RGB camera then takes three separate exposures using red, green, and blue filters to re-create the correct tonal balance on the film.

Roadway Features--The drivable roadway depicted throughout the entire scenario was classified into two highway types: major arterial (four-lane undivided roadway) and rural expressway (four-lane divided roadway). The roadway consisted of 12-ft traffic lanes separated by dashed lane lines conforming to typical highway standards (10-ft dashes, 30-ft gap length) with outside edges delimited by continuous solid lines. Rural pxressways consisted of two lanes in each direction separated by 50-ft medians. Track of the vehicle centerline was generally constrained to within 5 ft outside the right edge boundary and 5ft to the left of the centerline. "Crash" boundaries were set at these limits, with exceedance accompanied by a crashing sound and a temporary freezing of vehicle movement on the roadway.

Roads intersecting the main road at various angles were used to provide a realistic simulation of situations of different complexity and to provide appropriate contexts for some signs; e.g., merging traffic signs, exit signs, and guide signs. Road section configurations are shown with dimensions in Figure 4. Curvature used in this experiment was based on the expected approach speed for a given section of the roadway. American Association of State Highway and Transportation Officials (AASHTO) design standards were used in the design stage of the roadways. (6) Elements which had to be designed include lane width, shoulder width, and median width. Note that design values were not maximized but were maintained within he minimum range in order to keep the scenario length short so drivers would not be influenced by an sort of fatigue as might be encountered on a very long test run. Most signs were shown on tangent sections of the roadways.

A variety of intersection streets were shown during the driving scenario, especially on the four-lane undivided arterial roadway. These intersecting streets were dummies and not drivable. Any attempt to go into the intersecting streets (dummies) caused the vehicle to crash and freeze up before it was automatically set back on the drivable roadway. However, subjects were alerted to this fact and were not advised to enter cross streets, unless they were asked to do so. A presentation of the driving scenario roadway is shown in Figure 5.

Speed limit violation check points (flags) were set at random locations on the roadway. A speed limit risk factor of 0.5 was specified for the entire scenario. This means speed trap zones were set only 50 percent of the time on a random basis by the computer. Speed limit signs were placed on all roadways where appropriate. The enforced speed limit was actually 5 mph greater than that shown on the sign. Therefore, vehicles driving at 50 mph in a 45 mph speed zone had only 50 percent chance of getting "caught." A speed violation was indicated by a police siren sound; this did not stop until the driver slowed down to the speed limit indicated on the sign. Vehicle speedometer was set not to exceed 25 mph above the speed limit even though drivers could try to exceed this limit.

Experimental Procedure

The eight signs of interest were classified into two sign groupings: active advance warning signs and passive warning signs. Other types of traffic control devices were also seen located along the roadway. Sings of interest were positioned in advance of two operational locations; (1) intersections

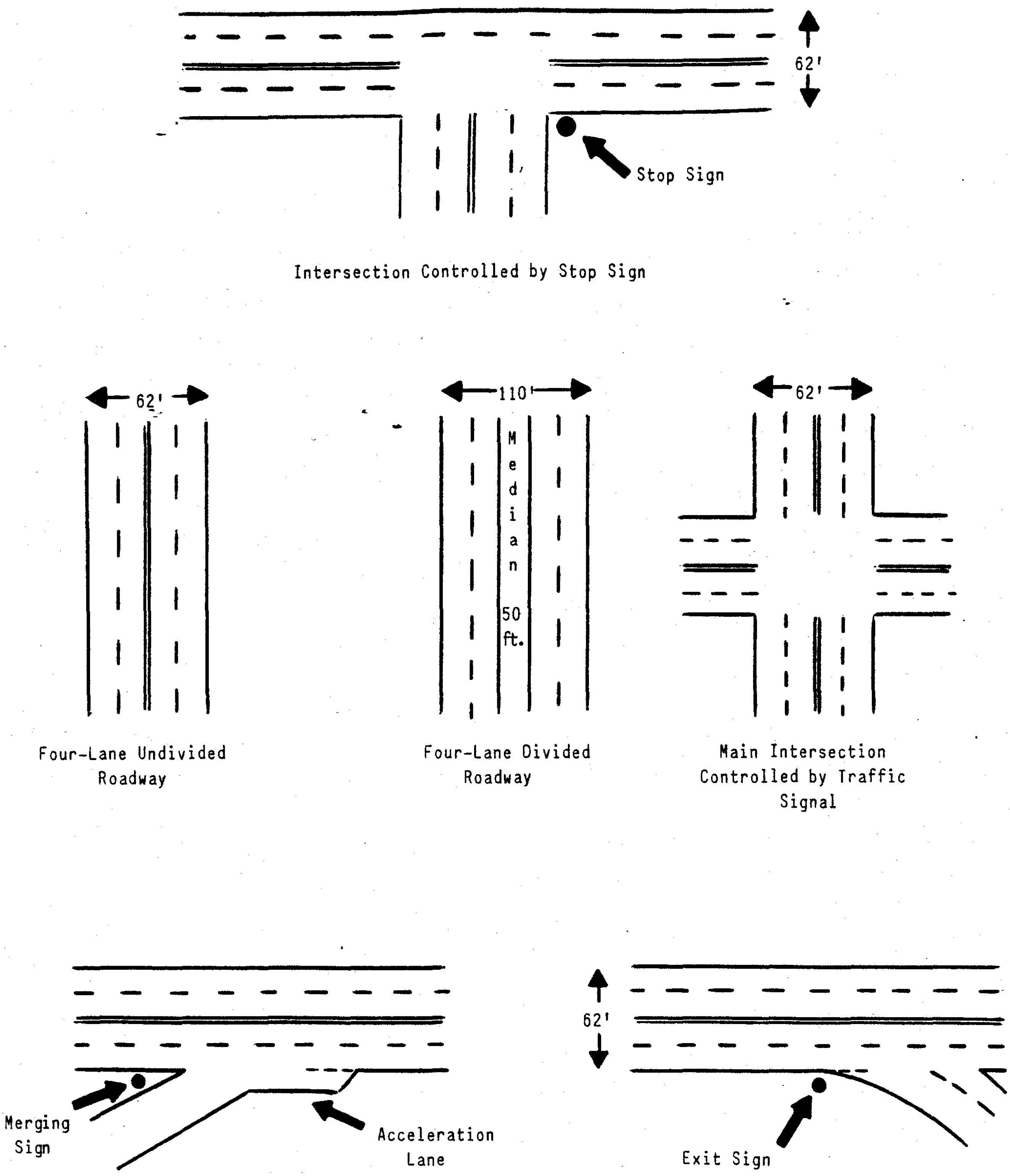
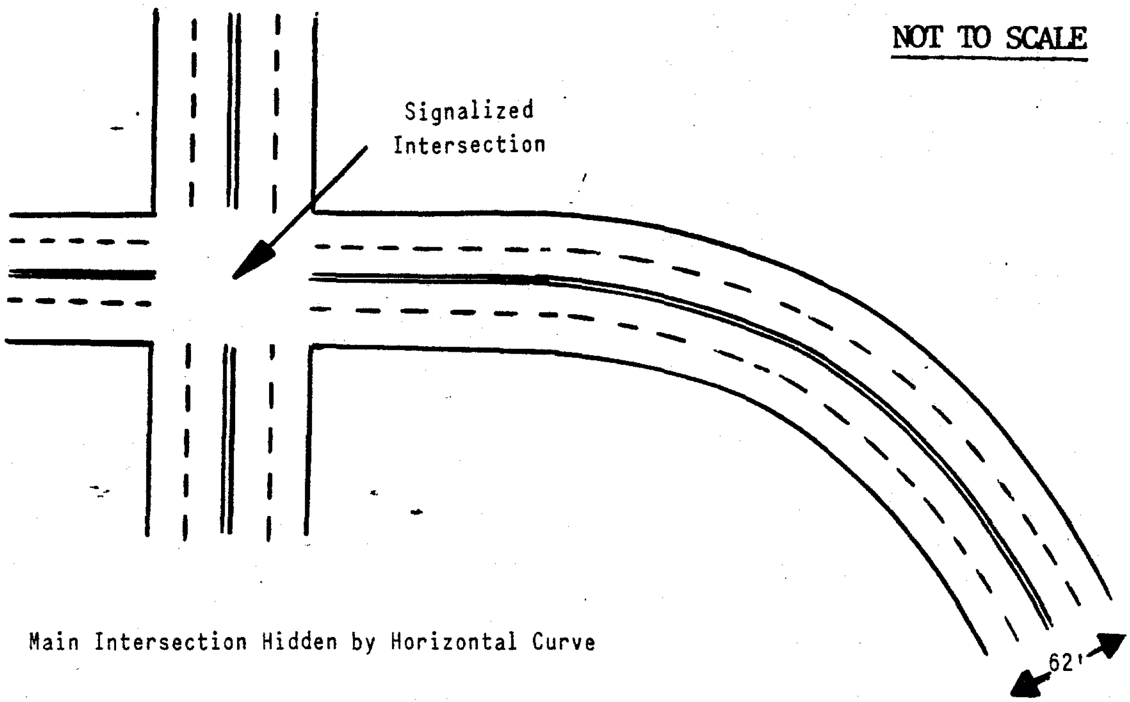


Figure 4. Sketches of Road Section Configurations Designed on the HYSIM.

NOT TO SCALE



Main Intersection Hidden by Horizontal Curve

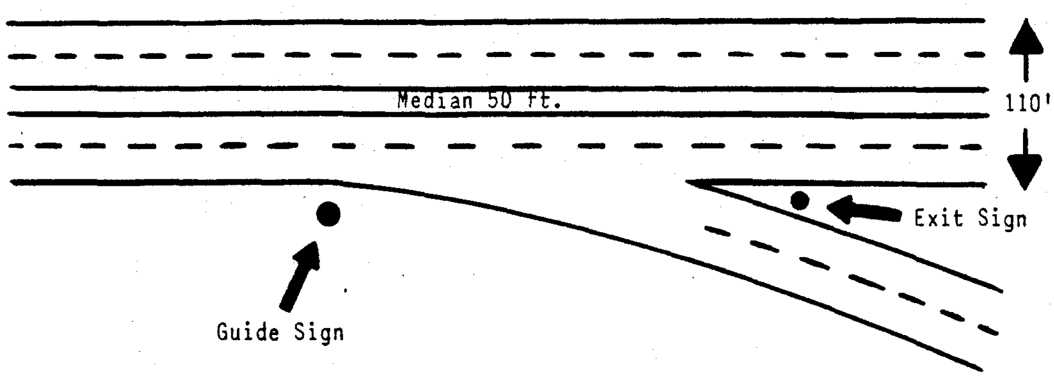


Figure 4. (Cont'd.)

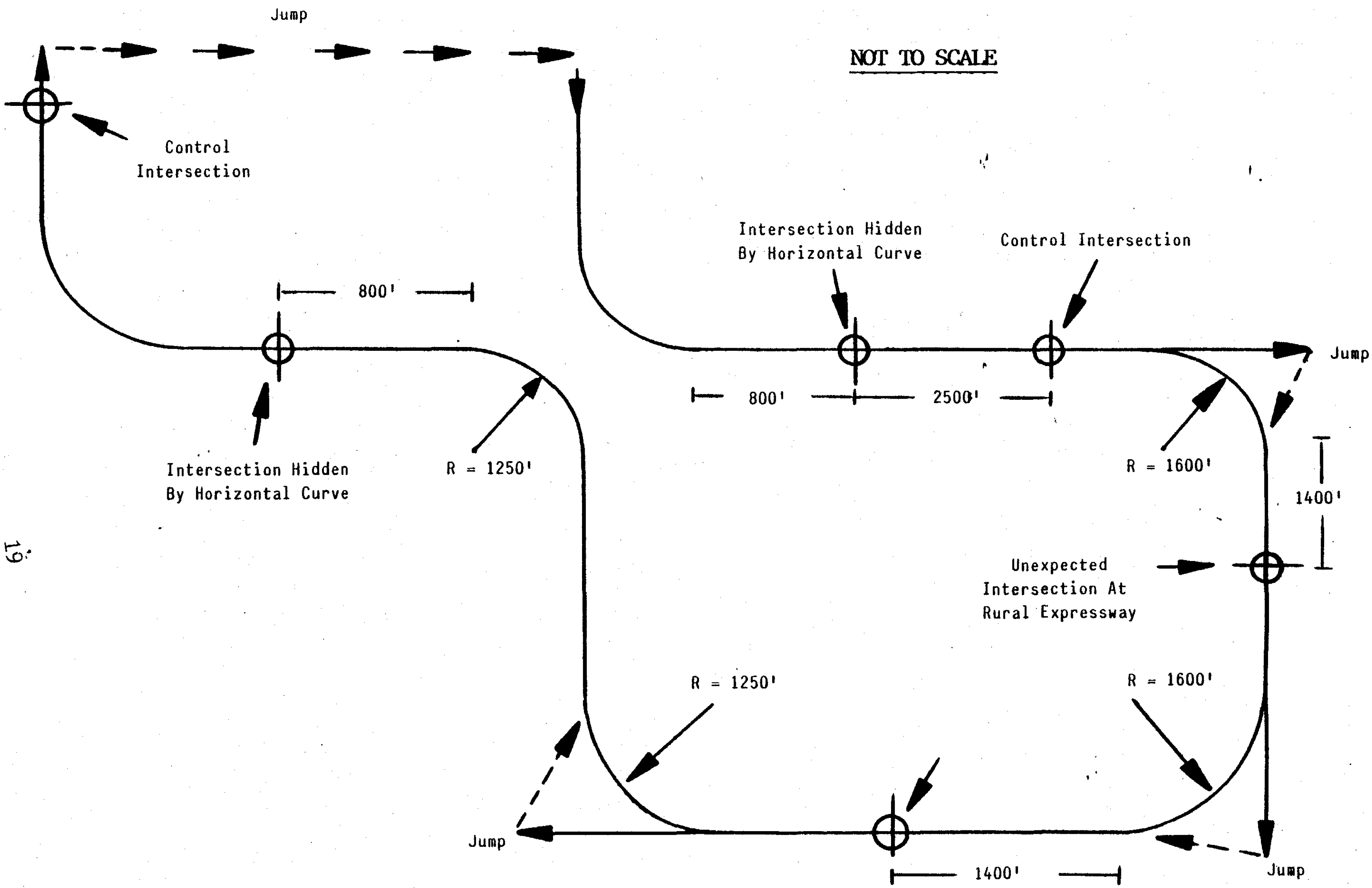


Figure 5. Sketch of the Driving Scenario Roadway.

hidden by horizontal curves and (2) rural expressways where high-speed intersections were unexpected. Each of the eight signs was presented once in advance of each operational location. Therefore, each sign was shown twice in the whole driving scenario. Other standard signs such as merging traffic signs, stop signs, yield signs, and slippery road signs, among others, were seen consistent with roadway geometry. All signs were presented to each subject in one clear visual condition and only in nighttime driving. Subjects knew that they would be the only vehicle on the roadway with no other street lighting or other source of light other than their vehicle's headlights. Speed zones were consistent with the road classifications. Major arterial streets had seed limit signs of 45 mph, while the rural expressways had 55 mph speed limit signs.

Data for the eight signs and two operational locations were obtained for 60 subjects who were grouped by age and sex. Additional information on subject selection, training and testing procedures, and sample size determination will be presented later in this section. Males and females were equally represented in all age groupings so that sex could be examined as a factor.

Signs were presented as a sequential part of a continuous roadway (the road looped on itself). However, certain changes such as different roadside features, exit geometry, street signs, and guide signs were used in every loop to minimize the "warm-up" effect whereby performance improved with each successive sign encountered if the same loops were kept with no change in roadway features. During each of the two driving sessions, subjects were exposed to several signs, but were only asked to respond to those that were tested.

Measures of Effectiveness

As pointed out earlier, each sign was presented as a sequential part of a continuous four-lane divided/undivided roadway. In most cases, more than one sign was visible at any one time. Therefore, drivers had to make a complex decision when more than one sign was seen at one time. As part of this study, the following measures wee considered to assess the effectiveness of active warning signs at high-speed signalized intersections; identification distance, reaction time, vehicle approach speed, and vehicle lateral placement.

Identification Distance--Identification distance is defined as the maximum distance at which drivers, headed twoard the intersection, can see and identify the stimulus (sign) correctly.

An ideal traffic control sign is designed to display information which conveys a particular message. If the intended message is to be identified and comprehended quickly, the information must be simple and legible. Frequently, drivers are faced with situations were they do not have much time to scan for highway signs. Therefore, it is appropriate to provided highway signs at locations where identification distance can be maximized. Providing a long range to identify highway signs would give drivers more time to comprehend the sign correctly; thus drivers have more time to concentrate on the driving task. This aspect of driver performance was completed on the HYSIM for both active warning and passive signal ahead signs.

Subject drivers were advised (through the highway simulator experiment description, Appendix A, and through the training session) to activate the headlight dimmer switch every tie they saw and could identify a sign that warned them of an oncoming traffic control signal at intersections. A schematic representation of identification distance is shown in Figure 6. Besides the flashing test signs (AAWS), several other flashing dummy signs wee incorporated on the HYSIM; such as, the flashing "NARROW BRIDGE" sign, the flashing "WORK ZONE" sign, and the flashing "SCHOOL ZONE" sign. Data were not collected for these dummy signs, but their addition to the scenario provided more realism and complexities in terms of real-life driving conditions. On the HYSIM, subject drivers were faced with a choice decision every time they activated the headlight switch. Subject drivers were trained to operate the headlight dimmer switch before they took part in the experiment. However, subject drivers did not see any of the test signs in the training scenario. Operating the dimmer switch caused the longitudinal distance from the vehicle to the sign to be recorded. The longitudinal distance to the sign was the distance traveled to the sign after the sign was identified. the headlight dimmer switch is located at the end of a lever on the left side of the steering column and is operated by pulling the lever toward the driver until a click is heard. Only one click caused the identification distance to start recording.

Only dta for those signs that were identified correctly were used. However, failure of a subject to identify these particular test signs correctly resulted in a $1 reduction in pay for every misidentified sign. Because the penalty imposed on drivers for misidentifying a test sign was extremely large, it was likely that drivers would pay much more attention to identifying the sign correctly.

Reaction Time--Reaction time is defined as the time required to process and respond to a stimulus. when subject drivers approached signalized intersections, they observed several signs before reaching the intersection. Among these signs was one of the test signs. When drivers reached the decision zone, the light display on the traffic signal changed from green to yellow. Following the change in signal display, it was anticipated the subject drivers would either brake to a stop or accelerate to proceed through the intersection would either brake to a stop or accelerate to proceed through the intersection before the red display was indicated. Reaction times were measured from the time the yellow indication was displayed on the traffic signal to the time subject drivers either initiated deceleration or acceleration motions. A schematic representation of reaction time measurement is shown in Figure 7.

In real life, the payoff for drivers making a decision to stop or to go is the safety risk; however, on the simulator the payoff was the penalty imposed on subject drivers. Penalties involved either a $1 reduction in pay for each time drivers entered the intersection on the red indication or a $0.25 reduction in pay for each minute delay in travel time.

Reaction time data were collected by age and sex groupings, for each test sign and at two different locations: intersections hidden by horizontal curves and intersections on rural expressways.

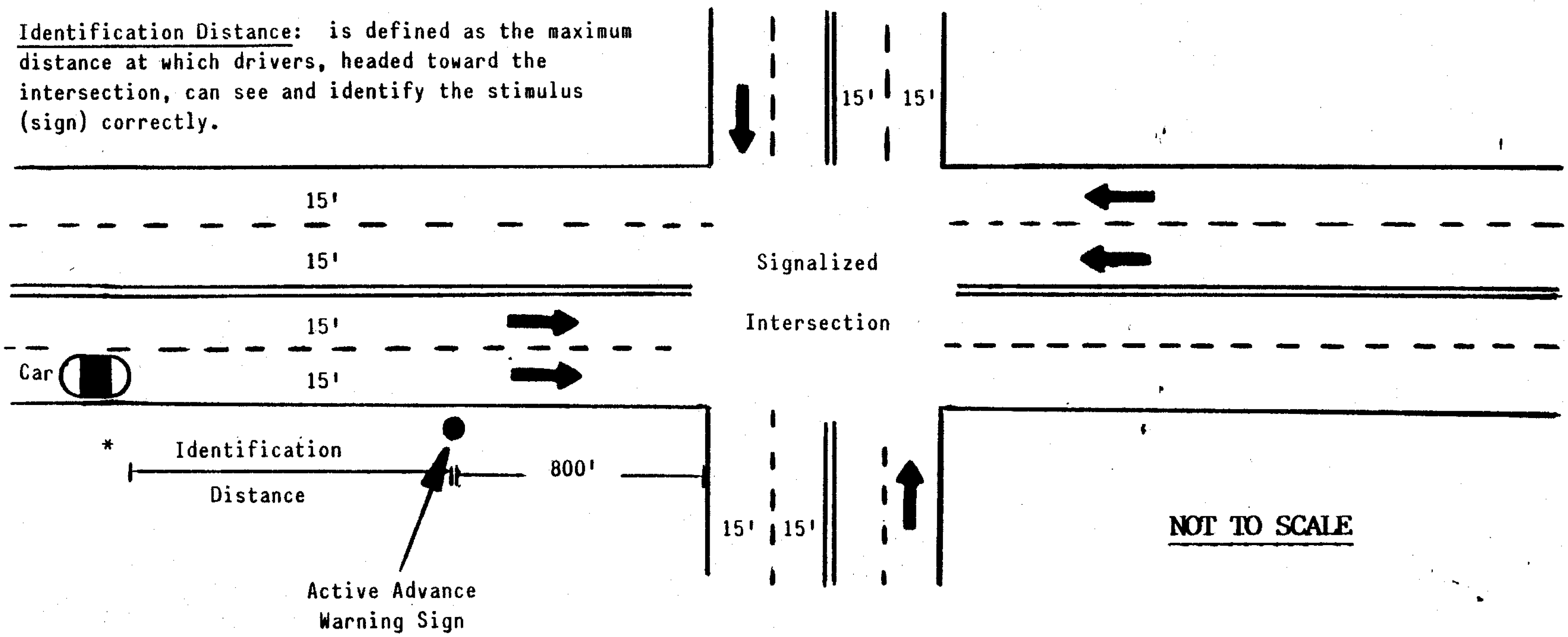


Figure 6. Schematic Representation of Measurement of Identification Distance.

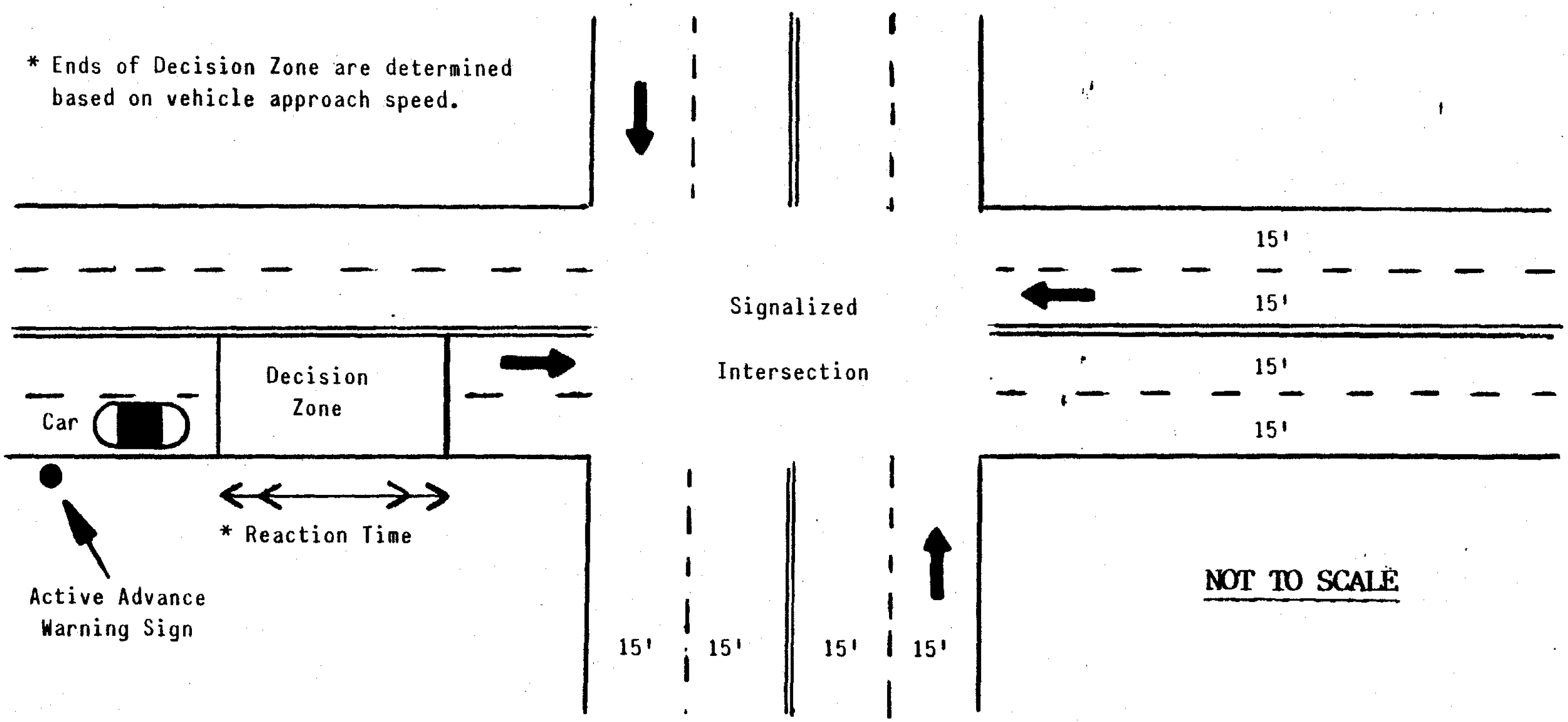


Figure 7. Schematic Representation of Reaction Time Measurement.

Vehicle Approach Speed--Vehicle approach speed was defined as the speed (in units of feet per second) at which subject drivers approached a given sign in moving toward the intnersection. Vehicle approach speed was measured at 25-ft intervals in each of three z ones; these speed zones are shown graphically in Figure 8. Speed zone 1 was defined as the distance traveled by approaching vehicles from the time the signs were projected or shown to the time approaching vehicles passed the signs. Speed zone 2 started when subject drivers passed the test signs but before they entered the decision zones at both locations: intersections hidden by horizontal curves and at unexpected intersections on rural expressways. Speed zone 3 was recorded for vehicles entering the decision zones and clearing or not clearing the signalized intersections. Length of these speed zones are shown in Appendix B.

Overall, speed data were recorded for three zones: before subject drivers passed the test signs, after they passed the signs but before they entered the decision zone, and after they cleared the decision zone. Data from the first two zones were used to compare directly before and after vehicle s speed reduction. Data from speed zone 3 was used to record vehicle deceleration rates for those who entered the decision zones and stopped at the intersections and for those who did not. Deceleration rates were compared with similar laboratory and field studies conducted previously.

Vehicle Lateral Placement--For the purpose of this study, vehicle lateral placement was defined as the lane deviation produced by subject drivers driving on the simulator at 25-ft intervals and every time subject drivers approached a test sign. The vehicle center line was considered as the reference line for recording lane deviation. Recording of vehicle lateral placement started as soon as the sign was shown on the roadway and stopped exactly 600 feet past passed the sign location.

Driving a car in real life or on the simulator requires continuous control of the steering task. However, in certain situations, roadside objects could demand significant amounts of attention such that driver awareness of the steering task could be minimized. Too much vehicle lateral placement (lane deviation) can be dangerous especially on high-speed roadways and where traffic volumes are high. Vehicle lateral placement is influenced by several factors such as sign position (ground-mounted or overhead), line of sight, sign type (warning, regulatory, or guide signs), and sign contents. Therefore, it is important that highway signs be placed in positions where they can be best seen and expected by drivers. For example, in this experiment, several ground-mounted signs were compared to several overhead signs. Also sigh contents should be short, simple, visible, and readable; otherwise, drivers will have to spend more time finding and reading the sign.

The purpose of collecting vehicle lateral placement data was to record lane deviation information for each sign and to determine which of the test signs showed the least deviation variability. Signs with minimum lane deviation would provide more efficient and safer driving operation than those which experienced high lane deviation variability.

Questionnaire Data--The questionnaire data collected in this study consisted of two parts: An active advance warning signs (AAWS) questionnaire and a simulator system evaluation questionnaire. The AAWS questionnaire was

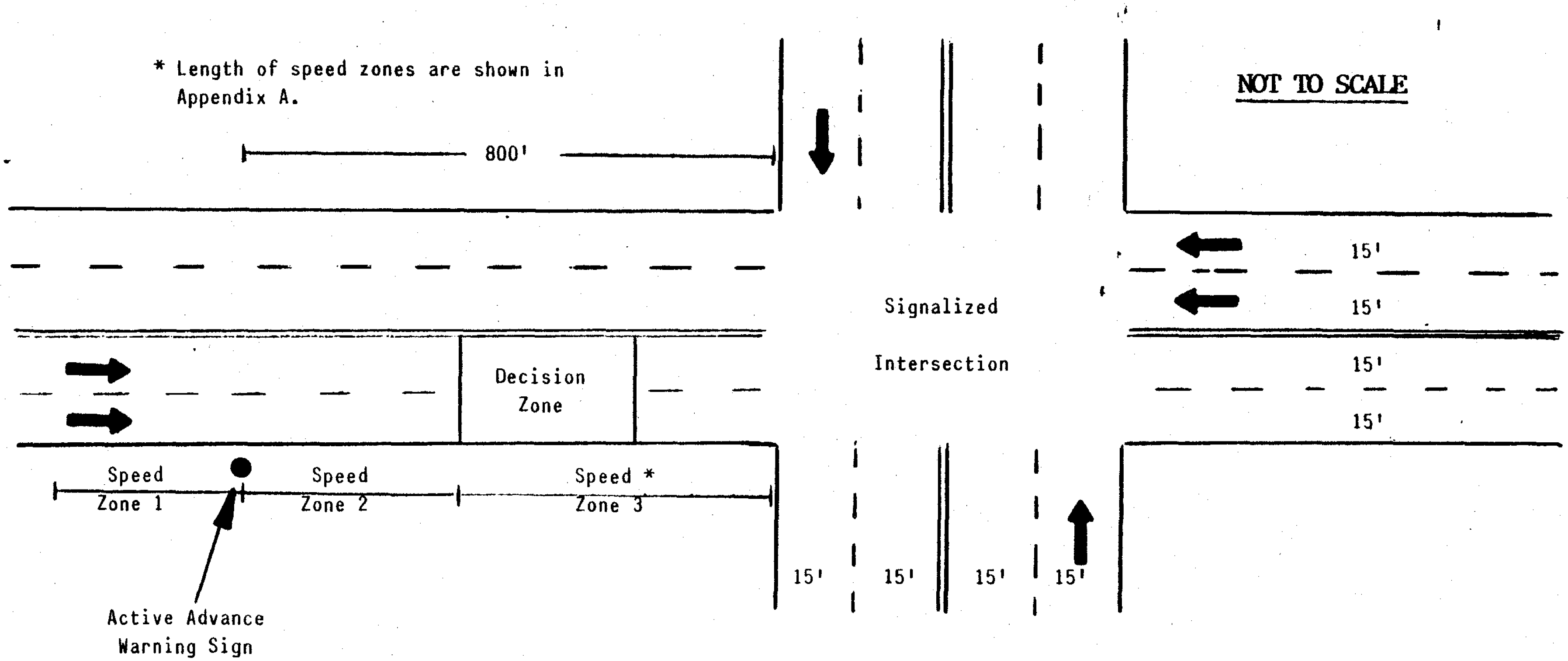


Figure 8. Schematic Representation of Vehicle Approach Speed Measurement.

designed to draw inferences on driver preferences relative to AAWS. Since such information had never been gathered before, the questionnaire was considered to be vital part of the study. Drivers were given the chance to judge active warning signs and to indicate there preferences based on their judgment and driving experience. The active warning sign questionnaire consisted of two sections. Section 1 asked questions based on the driver's experiences in the simulator; Section 2 included questions based on real-life driving experience. The AAWS questionnaire is presented in Appendix C.

The system evaluation questionnaire was considered as a part of the system criteria that relate to the FHWA HYSIM. In other words, such information would reflect something about the degree to which the driving simulator achieved what was intended to be achieved; such as realistic generation of simulated roadways, signs, and roadside features. Subject drivers were asked several questions on how they felt driving the simulator; they were also asked to judge signs and roadside simulated on the simulator, compared to real-life driving. The system evaluation questionnaire was considered as a standard form, since it was given to II subjects who made runs on the HYSIM, regardless of the particular research study in which they were participating. The system evaluation questionnaire is presented in Appendix C.

Subject Protocols and Procedures

This section describes the procedures employed to estimate the sample size for this experiment, the location and selection of subjects, the training and testing apparatus, and the reward/penalty scheme used in actual testing. Each of the above items will be discussed separately.

Sample Size Determination--Sample size required to estimate the standard deviation of this experiment was used on data obtained from a pilot study conducted on the simulator. The pilot (preliminary) experiment, a scaled-down version of the main experiment, was conducted using six subjects to obtain driver performance data. The sample means conducted from the pilot study provided estimates of population means and the error mean squares as an adequate estimate of population error variance. The six subjects used in the pilot study were classified from one age and sex group so that variation in performance data would be minimized, and thus providing a conservative estimate of the sample size used in this experiment. The standard deviation obtained from the pilot run was used to make a rough estimate of the critical sample size to be used in the main experiment. An illustration of this procedure is shown in Appendix D. This procedure provide a balance between type I error (α), probability that the null hypothesis, H_0, is rejected when H_0 is accepted when in fact the H_0 is true, and type II error (β), probability that the null hypothesis, H_0, is accepted when in fact the H_0 is false. The procedure provide a way of determining the required sample size that would be able to detect treatment effects of specified magnitude under the assumption of equal variances with sufficient power ($1-\beta$), 80 percent. For a significance level of $\alpha = 0.05$ and a power of $(1-\beta) = 0.08$, the required number of subjects was 60.

Subjects were classified by sex and age. Three age groups are as follows: Group I (16-30 years); Group II (31-50 years); and Group III (greater than 50 years in age). Therefore, ten subjects were assigned in each of the six categories. A representation of the sample size by age and sex groups in shown in Figure 9.

It should be noted that sample size for this experimental study was limited due to the fact that all subjects were paid for their participation. Because funds available for this propose were limited, sample size suffered somewhat from the loss of a higher degree of experimental power. However, this limitation can be compensated by manipulating either type I error (α) of type II error (β) or lower of the experiment.

Subject Selection--Subjects were solicited through advertisements in local newspapers. Also, subjects who had participated in previous studies on the HYSIM or other laboratory studies were contacted to determine their interest in participating in another study. In spite of the availability of several other procedures for locating subjects, such as random telephone calling or advertising in local stores and churches, the procedure employed in this study provided a rapid approach to location and scheduling subjects. Other procedures would not have provided a large sample in the limited period of time allowed for this study. Although a few subjects who participated in this study were participants in previous laboratory studies involving the simulator, they did not see any familiar objects on the HYSIM. The only advantages that they would have had compared to new participants was familiarity with the steering control on the HYSIM. Efforts were maintained to help new participants feel comfortable with the steering control task on the HYSIM through practice sessions; therefore, the effect of experience was minimized.

Subjects were screened when they called in response to the publicity to establish that they had a valid drivers license and no serious visual or other physical problems that would affect their ability to take part in the experiment and to establish their sex, age, and availability.

Upon arrival at the simulator location, a biographical information form was filled out by subjects to obtain driving experience and other background information. A summary of the biographical information form is resented in Appendix E.

To determine subject visual capbilities, far visual acuity, near visual acuity, and color vision, tests wee administered using the orthorater test instrument. A Snellen value of 20/33 was determined as the cut-off value in screening subjects on the basis of sufficient visual ability. A summary of the information acquired via the orthorater test equipment is shown in Appendix E.

As discussed previously, subjects were then scheduled for the experiment based on the previously stated sex and age groupings and on their stated availability. The tested subjects involved a variety of groups including students; engineers; full-time, blue- and white-collar workers; and retirees. Although a wider variety of subjects could have been obtained, it is not clear that the effort involved in recruiting these subjects would be worth the benefit of additional reduction in bias. The magnitude of bias of this type was expected to be minimal.

60 SUBJECTS

30 Males			30 Females		
Age Groups			Age Groups		
Group I	Group II	Group III	Group I	Group II	Group III
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X
X	X	X	X	X	X

(X) - represents one subject of each sex group per age group.

Figure 9. Presentation of Sample Subjects by Sex and Age Group.

Training and Testing--Subjects were scheduled one at a time on the simulator. Upon arrival, subjects were welcomed by the test administrator and were asked to examine a collection of the art work, developed from the same equipment used to make the sign slides that were seen on the HYSIM, so they could feel comfortable. Subjects were encouraged to ask questions about the experimental purpose and procedures. Next, subject ts completed the biography form and took the orthorater test. The next step was to review with them the highway simulator experimental description and to make sure they understood the literature on the experiment. The test administrator reviewed the three pages of this literature by reading and asking questions to make sure everything was clear. A summary of the highway simulator experiment description is shown in Appendix A.

When subjects appeared comfortable with the experiment description, they were introduced to the FHWA HYSIM and each subject drove a training scenario. Training on the HYSIM continued until subject appeared comfortable driving the simulator. The training scenario contained some of the signs used in the experiment, but not any of the tested flashing warning signs. Training on the HYSIM was done in several steps. Subjects were first asked to get a feel for driving the car. When subjects and acclimated themselves to driving, they were asked to respond to the signs as soon as they could identify them. The duration of training varied between subjects. however, the test administrator made sure that all subjects felt comfortable before they proceeded to the actual testing task. The training part of this test on the HYSIM provided the opportunity to examine the susceptibility of subjects to motion sickness. Those subjects who experienced motion sickness were asked to stop at their convenience; they were rewarded before they left the laboratory station. Motivation was maintained by a formal reward/penalty scheme as discussed in the following section.

Subjects were told that they would be tested on two sessions; each session was approximately 30 minutes long. Subjects were allowed a 10-minute break between sessions. Upon their return for the next session, the remaining part of the test was administered. When subjects finished participating in the test, they were rewarded, as discussed in the following section, and were asked whether they were willing to anticipate in future experiments.

After finishing their second run, subjects were asked to fill out the simulator evaluation for (Appendix C) nd were also asked to complete the AAWS questionnaire designed to provide preference information on active warning signs (Appendix C).

Reward/Penalty Scheme--the reward/penalty scheme used in the experiment was designed to motivated subjects to:

- Recognize signs accurately and respond to them quickly.
- Drive at the speed limits.
- Drive carefully with no potential crashes.
- Award subjects for participating in the experiment.

The reward/penalty scheme consisted of the following:

- A fixed reward for completing the two sessions.

- A fixed reward for completing the two-part questionnaire.
- A reward for completing the two sessions with no travel time delay, no speeding tickets, and no accidents.
- A fixed penalty for each speeding violation.
- A fixed penalty for each accident.
- A fixed penalty for not recognizing signs.
- A fixed penalty for travel time delay.
- A fixed penalty for going through red signals.

A summary of the reward/penalty scheme is shown in Appendix F. Rewards were paid in cash before subjects left the laboratory.

CHAPTER III

DATA ANALYSIS AND DISCUSSION OF RESULTS

Introduction and Overview

As described previously, this laboratory study was conducted to draw inferences about driver responses to and preferences in Active Advance Warning Signs (AAWS) at high-speed signalized intersections. The data collected consisted of two types: (1) objective data such as, sign identification distances, reaction times, vehicle approach speeds, and vehicle lateral placement and (2) subjective data, i.e., the AAWS questionnaire. Results presented here are based only on night-time driving conditions since this is what existed during the simulation runs. Results will be presented in the same order as the data were discussed in the previous chapter.

Sixty subject drivers were tested on the Highway Driving Simulator (HYSIM). Subject drivers wee classified by sex and age. The subjects tested represented a diverse group of people including full-time blue-and white-collar workers, students, and retirees.

Driver characteristics suchas, age, sex, driving experience, accident experience, and visual acuity were recorded for all tested subjects. The mean values of subjects' age and driving experience were 41 and 21 years, respectively. Several male/female subjects representing the younger age group wee as young as 17 years of age; other subjects were as old as 76 years of age and represented the older age group. In addition to the above, subject drivers were asked to report their driving experience and exposure such as, miles driven per week, percentage of freeway and city/rural driving, and number of accidents at high-speed intersections. The purpose of recording such data was t make sure that each of the tested drivers had adequate driving experience and exposure so that they would not be considered as new or unfamiliar drivers. Recorded data revealed that the mean mileage driven per week by 60 subject drivers was 150 miles. There was a split of 43/57 percent between freeway nd city/rural driving, respectively. A total of five accidents were reported by the sixty subject drivers.

Far and near visual acuity was recorded of reach subject driver so that subjects with poor visual acuity could be screened out. Only one male subject, 69 years of age, failed to meet the orthorate test with a cut-off value of 20/33. All other subjects passed the orthorater test successfully and thus completed the driving simulation test.

Identification Distance

Identification distance was measured as the maximum distance at which subject drivers, headed toward the intersection, could see indentify the stimulus (sign) correctly. A total of eight signs was tested: six dynamic (flashing) and two passive signs. The propose of collecting sign identification distance information was to examine which of the eight signs provided the greatest identification distance. Frequently, drivers are faced with situations where they do not have much time to scan for highway signs. Therefore, it is necessary to provide highway signs with messages and at locations where identification distance can be maximized.

Subject drivers were advised to activate the headlight dimmer switch every time they saw and could identify a sign that warned them of an upcoming traffic control signal at an intersection. However, several subjects failed to identify some of the signs; thus, some missing observations were recognized. As a result of this the identification distance data were analyzed using the Statistical Analysis Systems procedure GLM, which is a general linear models programs. (7) The GLM approach, unlike an analysis of variance (ANOVA) approach, can del with missing observations. The GLM as utilized to detect significant differences in identification distance data due to main and interaction effects of age, sex, sign and problem location. Assumptions of the GLM were examined. The Kolmogorov-Smirnov test was used to examine normality and the F-max test was used to test for homogeneity of the data. Both tests were examined, utilizing the SAS package, and assumptions were found to be satisfied. Analysis of variance utilized by the GLM treated the design as a four-factor experiment, age (3-levels), sex (2-levels), sign (8-levels) and problem location (2-levels).

Eight different signs were shown at two problem locations: (1) intersections hidden by horizontal curves, and (2) unexpected intersections at rural expressways. The signs were classified by number as follows:

1 - PREPARE TO STOP WHEN FLASHING (ground-mounted, diamond shape)

2 - PREPARE TO STOP WHEN FLASHING (overhead, diamond shape)

3 - PREPARE TO STOP WHEN FLASHING (ground-mounted, rectangular shape)

4 - PREPARE TO STOP WHEN FLASHING (overhead, rectangular shape)

5 - flashing "RED" SIGNAL AHEAD

6 - flashing Symbolic Signal Ahead

7 - passive SIGNAL AHEAD

8 - passive Symbolic Signal Ahead

Male and female subject drivers observed there signs at two different locations. A sample of sign identification distance data is shown in Appendix G. A statistical summary of the sign identification distance data is shown in Table 1.

Table 1. Statistical Summary of Sign Identification Distance Data

N	Mean (ft)	Std. Dev. (ft)	Max. (ft)	Min. (ft)	15-percentile (ft)	50-percentile (ft)	85-percentile (ft)
886	308	116.30	582	10	172	312	415

Several hypotheses wee examined to detect the significance of sign, age, sex and location effects on identification distance. Analysis of variance results

Table 2. Analysis of Variance by The General Linear Model For Identification Distance Data.

Source	df	$F_{calc.}$		
Age	2	34.51	*	
Sex	1	1.98		
Sign	7	89.52	*	
Problem Location	1	0.08		
Age x Sign	14	1.87	*	**
Sign x Prob. Loc.	7	10.58	*	
Sex x Sign	7	0.85		
Age x Sex x Sign	14	1.48		
Age x Prob. Loc.	2	0.07		
Sex x Prob. Loc.	1	0.56		
Age x Sex x Prob. Loc.	2	0.19		
Age x Sign x Prob. Loc.	14	0.77		
Sex x Sign x Prob. Loc.	7	0.51		
Age x Sex	2	1.19		
Age x Sex x Sign x Prob. Loc.	14	0.43		

* Significant at $\alpha = 0.05$
** Not Significant at $\alpha = 0.01$

are showning Table 2. The null hypothesis (Ho:$\mu_1=\mu_2=\mu_3$) on age effects that the mean "identification distance of all three are groups is no different, was rejected. A multiple comparison procedure, least significant difference (LSD) test, was utilized to show differences between age groups. (12) Note that the LSD test controls the Type I comparisonwise error rate (the null hypothesis is rejected when in fact the null hypothesis is true). It was found that the mean identification distance of Age Group I was significantly different from both the Group II and Group II mean identification distance ($\mu_1 \neq \mu_2 \neq \mu_3$). Younger subjects (16-31 years) identified the signs much farther away than the middle age and older subjects. this outcome is consistent with other previous research findings, such as the ones identified in the literature review.

The null hypothesis (Ho:μsign1 identification distance =μsign2 identification distance = ...=μsign8 identification distance) was rejected. Therefore, at least one pair of the sign identification distance means was significantly different. A multiple comparison test are shown in Table 3. The Flashing Symbolic Signal Ahead sign was shown to be sign was shown to be significantly different with a greater identification distance than all other tested signs. The flashing "RED SIGNAL AHEAD sign had the next highest sign identification distance. However, these two signs were significantly different

Table 3. Multiple Comparison Test (LSD) For Identification Distances Between Signs.

SIGN	6	5	8	3	4	2	1	7
MEAN* (ft.)	449	353	351	301	295	239	238	222
	D	A	A	B	B	C	C	C

from each other. Also, it was found that the passive Symbolic Signal Ahead sign was significantly different from and better than the PREPARE TO STOP WHEN FLASHING Signs.

Furhtermore, the contrast procedure was used to detect difference between ground-mounted and overhead signs and between the passive and dynamic signs. (7) The contrast procedure provides a mechanism to construct and test linear functions of the parameters. for example, two groups can be tested and compared directly, rather than looking at each individual parameter of each group., As a result of this, it was concluded that sign position did not significantly affect the mean identification distance. However, the mean identification distance of dynamic signs (312 feet) was concluded to be significantly different from the mean identification distance of passive signs (286 feet). Dynamic signs demonstrated strater identification distances than passive signs. Apparently, it was the flashing lights that attracted the subjects attention and thus resulted in early detection and identification of the signs.

Since other main effects, such as sex and problem location did not affect sign identification distance significantly, interaction effects were also investigated. As far as interaction effects, age-sign and sign-problem location were found to affect sign identification distance significantly. In general, signs were identified farther away by younger drivers than they were identified by older drivers. Also, several signs seemed to be identified from a greater distance at unexpected intersections than they were identified from a greater distance at unexpected intersections than they were identified at intersections hidden by horizontal curve. However, the main difference between the sign location at both problem locations was the approach geometrics. Intersections hidden by horizontal curves were approached on a four-lane undivided roadway, while the other location was a four-lane divided roadway.

At either location, the missing observations on sign identification distance were attributed to the PREPARE TO STOP WHEN FLASSHING signs. However, these missing observations did not occur because drivers failed to see the sign, but because of driver confusion of the sin meaning.

Overall, the flashing symbolic Signal Ahead and the flashing "RED" SIGNAL AHEAD sign were the first identified signs. The PREPARE TO STOP WHEN FLASHING and the passive SIGNAL AHEAD sign were the most difficult to recognize among all signs studied.

Reaction Time

Reaction time was defined as time required to process and respond to a stimulus. When drivers reached the decision zone, the light display on the traffic signal changed from green to yellow. Following the change in the signal display, reaction times were measure from the time the yellow indication was displayed on the traffic signal to the time subject drivers performed either deceleration or acceleration actions.

A unique aspect of reaction time measurement on the HYSIM was the source and experimental validity of driver input. Unlike reaction time data collected in the field, where brake application or brake light indicators are condidered to be the base for recording reaction time, the procedure implemented on the HYSIM measured reaction time for every single vehicle observed, regardless of whether the brake light was observed or not. A deceleration/acceleration threshold value of $2/ft/sec^2$ was considered to measure drivers' reaction time every time the traffic signal indication changed from green to yellow.

Reaction time data were collected by age and sex groupings at two different locations: intersections hidden b y horizontal curves and intersections on rural expressways.

approximately 958 observations were collected. A sample summary of reaction time data is contained in Appendix G. Table 4 summarizes the mean values observed for reaction time by age, sex and problem location. Note that the reaction time values obtained in this study consisted only of driver perception and response time and did not necessarily include rake reaction and response lag time. The mean reaction time of all subject drivers in the subject population was 0.94 seconds. Table 4 shows that female drivers had longer, but not a statistically significant different, reaction times than for male drivers. Figure 10 shows the cumulative distribution of reaction times. Eighty-five percent of subject drivers reacted in 1.3 seconds or less

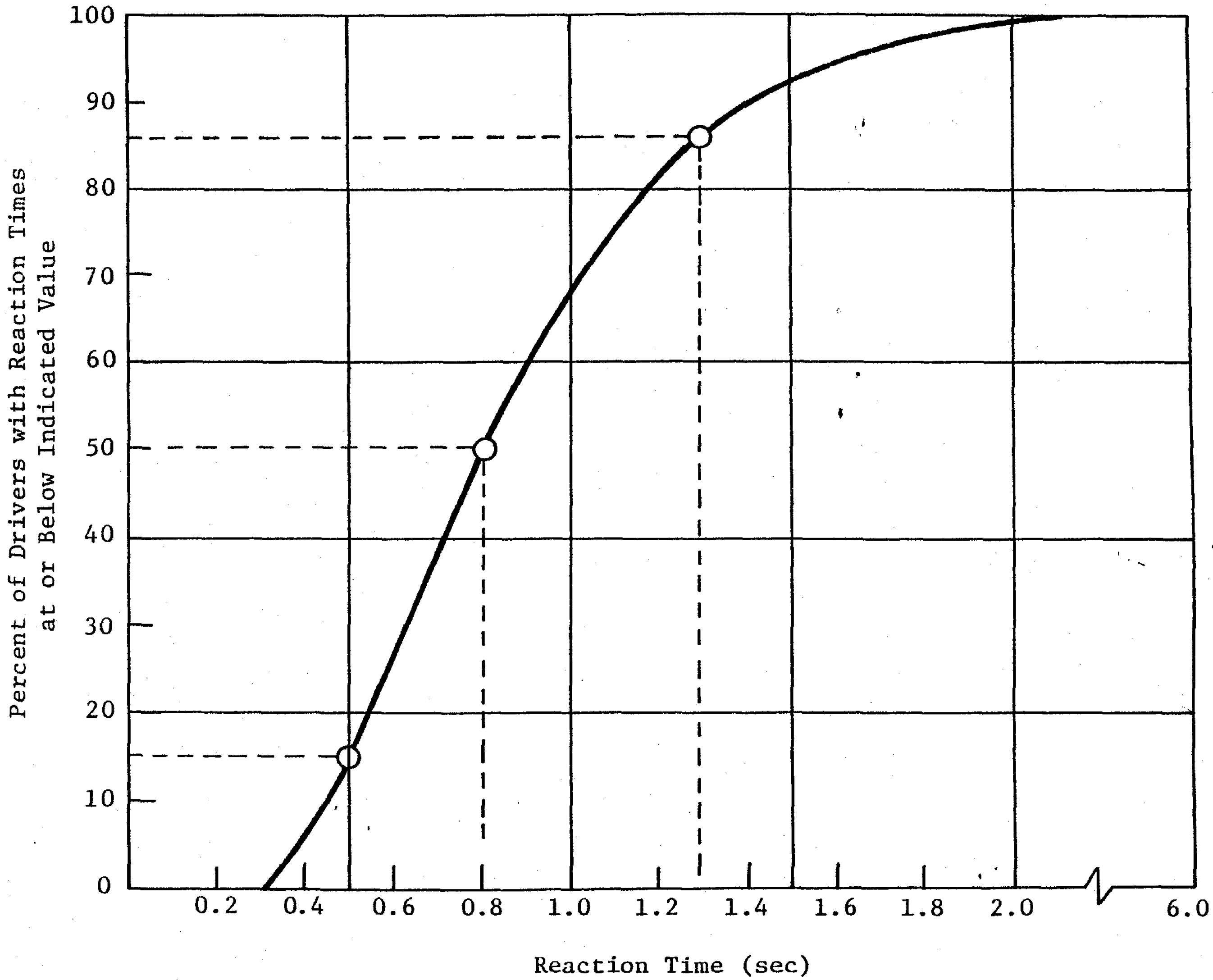


Figure 10. Cumulative Frequency Distribution of Reaction Times for Subject Drivers

to the yellow signal indiction. Fifteen percent of subject drivers reacted in 0.50 seconds or less. The median value of reaction times was 0.80 seconds.

Table 4. Mean Reaction Time (seconds) by Age, Sex, and Problem Location.

AGE			SEX		PROBLEM LOCATION		Overall Mean (sec.)
(16-30 yrs)	31-50 yrs)	(50 yrs)	Male	Female	Horizontal Curves	Rural Expressway	
0.910	0.990	0.920	0.903	0.975	0.86	1.017	0.94

The data obtained in this laboratory study seemed to match and compare well with similar studies reported in the literature.[8,9] However, the values obtained here were lower than values obtained in field studies. A comparison between means and 85-percentile reaction times for the current and two similar studies is shown in Table 5. Note that the other studies, conducted in the field, reported higher reaction time values. In general, this is an expected outcome since field studies include brake reaction and response lag time as part of their computed reaction time. The brake reaction and lag response time could vary between 0 and several seconds; such an additional interval can contribute to significant differences between laboratory and field studies.

Table 5. Mean Driver Reaction Times Reported by Various Research Studies.

STUDY / REACTION TIME	Sabra, (1985)	Chang and Messer(8) (1984)	Wortman and Matthias(9) (1983)
SAMPLE SIZE	958	579	____
MEAN (Sec.)	0.94	1.3	1.3
85-Percentile (Sec.)	1.3	1.9	1.8

A major drawback with measuring reaction times in the field is the fact that reaction time data are only recorded when a vehicle's brake light indicator is observed; otherwise, no measurement is observed. Drivers who decelerate without any brake application are usually not sampled. Similarly, reaction time is not measured for those drivers who accelerate. Such experimental methods suffer a great loss of validity and bias in sampling. However, the method implemented on the HYSIM did not omit any observations, i.e, all subject drivers were measured. It was, however, expected that reaction time values obtained on the simulator would be lower than those acquired in the field since they excluded brake reaction and lag response time.

In addition to the above analysis, the GLM was used to detect differences in reaction time that could have been caused by sex, age and location effects. A summary of the analysis of variance and computed results is shown in Table 6. It was concluded that the mean reaction times for all three age groups were not significantly different. Although female drivers experienced longer reaction times than made drivers, such differences were not statistically significant. However, the reaction time mean, as computed on the simulator, at intersections hidden by horizontal curves was significantly different from the reaction time mean at rural expressways. These results had been anticipated since very often drivers do not expect traffic control signals at rural expressways. Thus, reaction times at such locations are expected to be longer than at other locations.

Table 6. Summary of the GLM Procedure for Reaction Time Data by Age, Sex, and Problem Location.

Source	df	$F_{calc.}$
Age	2	1.72
Sex	1	3.06
Problem Location	1	14.41 *
Age x Sex	2	0.07
Age x Prob. Loc.	2	1.79
Sex x Prob. Loc.	1	0.84
Age x Sex x Prob. Loc.	2	0.18

* Significant at $\alpha = 0.05$

The reaction time data provided through this laboratory study were limited, due to the fact that drivers knew in advance that no other vehicles were present in the driving simulation test. Therefore, drivers were not faced with crucial situations where they had to make very quick responses involving other vehicles.

Vehicle Approach Speed

Vehicle approach speed was defined as the speed at which subject drivers approached a given sign in moving toward the intersection. Speed data were collected for three zones: (1) before subject drivers passed the test signs, (2) after they passed the test signs but before they entered the decision zone, and (3) after they cleared the decision zone. Speed data obtained from the first two zones were used to compare directly before and after vehicle speed reduction. Speed data obtained from the last zone were used to compute acceleration/deceleration rate data. Summary tables of vehicle approach speeds in the three zones and speed reduction data are shown in Appendix G. A statistical summary of vehicle approach speed, i.e., means, standard deviations and other outcomes are shown in Table 7.

Table 7. Statistical Summary of Vehicle Approach Speed Data.

VARIABLE	N	MEAN (mph)	ST. DEV. (mph)	MAX. (mph)	MIN. (mph)	PERCENTILE (%) 15	50	85
V_1 before speed	960	43.4	6.01	61.6	17	37.2	43.0	49.1
V_2 after speed	960	42.4	6.47	63.5	18.9	35.3	42.1	48.5
$V_1 - V_2$	960	-1.02	2.75	10.8	-14.7	3.5	-0.40	0.86

Initially, it was anticipated that a change in vehicle approach speed (speed reduction) is better than no change or than an increase in vehicle

Table 8. Analysis of Variance for Before and After Vehicle Speed Reduction (V_2-V_1) Data[2 1]

Source	df	$F_{calc.}$
Age	2	4.19 * **
Sex	1	0.68
Age x Sex	2	1.52
Sign	7	10.05 *
Age x Sign	14	0.88
Sex x Sign	7	0.59
Age x Sex x Sign	14	0.96
Problem Location	1	1.21
Age x Prob. Loc.	2	0.60
Sex x Prob. Loc.	1	0.41
Age x Sex x Prob. Loc.	2	0.36
Sign x Prob. Loc.	7	5.47 *
Age x Sign x Prob. Loc.	14	0.47
Sex x Sign x Prob. Loc.	7	0.80
Age x Sex x Sign x Prob. Loc.	14	0.70

* Significant at $\alpha = 0.05$
** Not Significant at $\alpha = 0.01$

approach speed, due to the effect of AAWS. Table 8 shows a summary of the analysis of variance for the before and after speed reduction data. The null hypotheses considered in this analysis centered on several main effects such as age, sex, sign and problem location. The null hypothesis associated with the age effect, that the mean speed reduction (before-after) for Age Group 1 is equal to the mean of Age Group 2 and Group 3, was rejected. Speed reductions experienced by the youngest subject drivers were the smallest among all age groups. This indicates that young drivers hardly slowed down after passing an active advance warning sign, while the middle age group of subjects slowed down considerably. Older subjects showed a response that was very similar to the youngest subject group. However, the oldest subject drivers approached the test signs at a relatively low speed that did not require them to slow down after they saw the signs.

The null hypothesis associated with the sex effect, that the mean of speed reduction by male subjects is not different from the mean of speed reduction by females, were examined. No statistically significant difference in means was found.

The mean speed reduction at intersections hidden by horizontal curves was found not to be statistically different from the similar mean at rural expressways.

As with the age effects on speed reduction, the null hypothesis on sign effect ($H_0: \mu_{sign1} = \mu_{sign2} = \ldots = \mu_{sign8}$) was rejected. Evidence revealed statistically significant difference in speed reduction data between signs. Further multiple comparisons between signs concluded that the passive symbolic Signal Ahead sign contributed the most to speed reduction between Zone 1 and Zone 2. This particular sign was shown to be the most effective sign in reducing vehicle approach speed, especially in Zone 2. The flashing symbolic Signal Ahead sign was the second most effective sign with mean speed reduction of approximately 2 mph. The PREPARE TO STOP WHEN FLASHING signs were the least effective signs in reducing vehicle speed.

Contrasting between ground-mounted and overhead signs did not reveal any significant differences. Basically, sign position and location did not affect before and after vehicle speeds.

Contrasting between dynamic (flashing) and passive warning signs revealed a statistically significant difference between the two means. In general, the dynamic (AAWS) signs were significantly different, and better, than the passive warning signs. Dynamic signs results in greater speed reduction than the passive signs. Apparently, drivers slowed down in a more rapid manner when they observed AAWS than when they observed passive signs. Practically speaking, some of the significant differences between signs can be attributed to the dynamic flashing of AAWS, especially their conspicuity. In most cases, drivers slowed down rapidly when they observed an AAWS and then maintained speed until they saw a traffic signal indication.

Although differences in the before/after speed data were statistically significant, the magnitude of such differences would not be practically significant in real-life driving conditions. In general, speed differences between means never exceeded 3 mph. Therefore, practically speaking, the AAWS are useful devices to maintain vehicle approach speed at high-speed signalized intersections but should not be installed because of speed problems.

In addition to the above results, the sign effect seemed to interact significantly with problem locations. For example, the flashing symbolic Signal Ahead and the passive symbolic Signal Ahead signs were significantly better in reducing vehicle speed at intersections hidden by horizontal curves then at rural expressway locations. It could not be explained why this result occurred, but rural expressway geometric have helped drivers considerably to maintain their high approach speed.

In addition to the above analysis, speed data were collected in Zone 3 so that acceleration/deceleration rates could be computed. Acceleration and deceleration data were collected following driver reaction to the change in the signal display. In most cases, the majority of drivers decelerated following the change in the signal display from green to yellow and then came to a complete stop; a few subjects (two-percent) accelerated and made it into the intersection before the red signal was displayed. Not that the change interval duration was 5 seconds during the entire study for all signalized intersections. A sample of deceleration data is shown in Appendix G. A statistical summary of acceleration/deceleration data is shown in Table 9.

Table 9. Statistical Summary of Acceleration/Deceleration Data.

VARIABLE	N	Mean fps^2	STD. DEV. (fps^2)	Max. (fps^2)	Min. (fps^2)	15-Percentile	50-Percentile	85-Percentile
Accel.	35	1.2	0.68	3.1	0.2	-	-	-
Decel.	925	5.20	2.75	17.5	0.1	3.0	5.1	9.0

The overall deceleration mean of subject drivers, who stopped after the yellow display, was 5.20 ft/sec^2. Eighty-five percent of subject drivers decelerated at a rate of 9 ft/sec^2 or lower; fifteen percent of the same subjects decelerated at a rate of 3.0 ft/sec^2, before they finally came to a complete stop. As far as the acceleration rate data, it was not really crucial for drivers to accelerate in order to make it through the intersection. During the five seconds of the yellow time, subjects driving at 45 or 55 mph could easily make it through the intersection. However, a few of the subjects experienced a large amount of hesitation whenever the yellow signal was displayed, and thus were trapped in the middle of the intersection. As a result of this hesitation, drivers were forced to go through the intersection when the signal display was red. Other drivers failed to make a stop/go decision when they were faced with the change display; they either decelerated at a very high rate (up to 17 ft/sec^2) or they were caught on the red signal display.

The data obtained in this simulation study are basically similar to data normally obtained in the field. For example, a typical stopping/deceleration rate, in the field, is 8-12 ft/sec^2. Most likely, drivers will not stop at traffic signals if they must decelerate beyond 12 ft/sec^2, but would choose to go through at a minimal acceleration rate. Note that driver characteristics have the biggest impact on driver actions and on situations that require rapid decisions.

To examine the effects of driver characteristics on deceleration rate, analysis of variance was utilized to test the effects of sex, age and problem location on deceleration data. The analysis of variance and a summary of computed results are shown in Table 10. The null hypothesis (H_0: decel. male = decel. female), that the mean deceleration rate experienced by male groups is equal to the one experience by female groups was rejected. Therefore, sufficient evidence is provided to conclude that the two means are significantly different from each other.

Similar to the sex effect, the mean deceleration rate was significantly different at rural expressways from that at intersections hidden by horizontal curves. Drivers tend to have a higher deceleration rate at rural expressways than at the other locations. This effect is primarily due to differences in vehicle approach speed. The posted speed limit at the rural expressways was 55 mph; the other location had a 45 mph posted speed limit. This conclusion supports the fact that vehicle approach speed is a significant issue when dealing with acceleration or deceleration rate data. Furthermore, the age-sex interaction effect was the only significant interaction effect. The older female group decelerated in a more rapid manner than the older male group. However, the younger female drivers decelerated at a much slower rate than male drivers. This particular issue was difficult to compare with other studies because none of the previous studies considered age, sex, or other driver characteristic effects. However, the Highway Driving Simulator demonstration appeared to be a valid and reliable source of obtaining deceleration/acceleration rate data.

Vehicle Lateral Placement

For the purposes of this study, vehicle lateral placement was defined as the lane deviation produced by subject drivers driving toward a sign and at a given speed. Lateral placement was measured from the left roadway edgeline to the vehicle centerline. For example, on a four-lane divided highway with 15-foot wide lanes, a vehicle driving in the center of the right lane would have a 15+ 15/2 or 22.5 foot lateral placement. A vehicle driving in the center of the left lane would have a 15/2 or 7.5 foot lateral placement.

Table 10. Analysis of Variance for Deceleration Rate Data.

Source	df	$F_{calc.}$
Age	2	0.91
Sex	1	9.36 *
Age x Sex	2	15.46 *
Problem Location	1	8.94 *
Age x Prob. Loc.	2	1.20
Sex x Prob. Loc.	1	0.56
Age x Sex x Prob. Loc.	2	0.95

* Significant at $\alpha = 0.05$

The purpose of collecting vehicle lateral placement data was to record lane deviation data for each active and passive sign, and to determine which of the test signs would provide the least lateral placement deviation. It was expected that some of the signs might have significant impact on vehicle lateral placement because of their long word message and position. For example, the PREPARE TO STOP WHEN FLASHING signs were expected to take longer to read and comprehend correctly; therefore, more driver attention is required and this can result in vehicle lateral placement which could be either significant or not significant.

As discussed previously, vehicle lateral placement data were recorded 600 feet before each tested sign was depicted and 600 feet past the test sign location. A sample of vehicle lateral placement data is shown in Appendix G. A statistical summary of before/after vehicle lateral placement data is shown in Table 11.

Table 11. Statistical Summary of Vehicle Lateral Placement (VLP) Data.

VARIABLE	N	Mean (ft)	STD. DEV. (ft)	Max. (ft)	Min. (ft)	15-Percentile	50-Percentile	85-Percentile
Pre-VLP	960	21.35	1.42	24.8	12.5	20.0	21.3	22.75
Past-VLP	960	21.33	1.24	24.8	14.3	20.3	21.3	22.50
(Past-Pre)VLP	960	0.012	0.945	3.9	-3.4	-1.0	0	0.93

An analysis of variance was conducted to examine the effects of age, sex, sign and problem location on lateral placement reduction. A summary of the analysis of variance and computed results are shown in Table 12.

Table 12. Analysis of Variance for Before/After Vehicle Lateral Placement.

Source	df	$F_{calc.}$
Age	2	2.53
Sex	1	4.91 * **
Sign	7	3.39 *
Problem Location	1	146.16 *
Age x Prob. Loc.	2	5.24 *
Age x Sex	2	2.66
Age x Sign	14	0.63
Age x Sex x Sign	14	1.23
Sex x Prob. Loc.	1	2.64
Age x Sex x Prob. Loc.	2	1.05
Sign x Prob. Loc.	7	1.49
Age x Sign x Prob. Loc.	14	0.53
Sex x Sign x Prob. Loc.	7	0.91
Age x Sex x Sign x Prob. Loc.	14	1.21

* Significant at $\alpha = 0.05$
** Not Significant at $\alpha = 0.01$

The null hypothesis associated with the age effect (μpast-pre(age1) = past-pre(age2) = μ past-pre(age3)) that the means of lateral placement reduction associated with the three age groups are not different, was not rejected. No significant differences were observed between the three age groups.

A similar analysis was conducted to examine the null hypothesis (H_0: μpost-pre (male) = μpost-pre (female) of sex effects on vehicle lateral placement. There was sufficient evidence to conclude that both means (male/female) of vehicle lateral placement were significantly different. In general, female drivers experienced less lane deviation than male drivers.

The null hypothesis associated with location effect on vehicle lateral placement was examined. The null hypothesis (Ho:μpast-pre (loc 1) = μpast-pre (loc 2) was rejected. It was found that the mean (0.35 ft.) of vehicle lateral placement at intersections hidden by horizontal curves was significantly different and greater than the mean (0.32 ft.) of vehicle lateral placement reduction at rural expressways.

As discussed previously, the main intention of recording these data was to examine the effects of active and passive warning signs on vehicle lateral placement. Therefore, the null hypothesis tested in this analysis (Ho: μ past-pre (sign 1) = μ past-pre (sign 2) = ... = μ past-pre (sign 8)) that the mean of vehicle lateral placement reduction encountered at sign 1 is equal to the mean encountered at sign 2 and so forth for the rest of the signs. As was expected, the null hypothesis (H_0) was rejected, and at least one pair of the aforementioned means was statistically significant and different from the remaining means.

Table 13 presents a comparison of computed means and rank by sign. A multiple comparison procedure revealed that the flashing "RED" SIGNAL AHEAD sign contributed the least vehicle lateral placement variability, while the flashing Symbolic Signal Ahead sing had the highest variability of vehicle lateral placement among all tested signs. It could not be explained, however, whether such significant differences were caused by sign location, driver characteristics of other variables associated with the Highway Driving Simulator.

Therefore, further contrast analysis was conducted to detect any significant differences due to sign location or the sign activation mechanism. A contrast analysis was conducted for ground-mounted versus overhead signs. It was found that the mean vehicle lateral placement reduction associated

Table 13. Comparison of Vehicle Lateral Placement Results.

SIGN	Post-pre/vehicle lateral placement mean(*)	Rank
PREPARE TO STOP WHEN FLASHING (G-mounted, Diamond Shape)	0.11917	6
PREPARE TO STOP WHEN FLASHING (overhead, Diamond Shape)	0.16167	7
PREPARE TO STOP WHEN FLASHING (G-mounted, rectangular Shape)	0.10750	4
PREPARE TO STOP WHEN FLASHING (overhead, rectangular Shape)	0.06250	3
Flashing "RED" SIGNAL AHEAD	0.00167	1
Flashing Symbolic Signal Ahead	0.275	8
Passive SIGNAL AHEAD	0.11917	5
Passive Symbolic SIGNAL AHEAD	0.05583	2

with ground-mounted sings (0.13 feet) was significantly different from the mean of vehicle lateral placement reduction associated with overhead sign (0.112 feet). Apparently, overhead signs caused less lateral placement deviation.

Similar to the above contrast analysis, dynamic (flashing) signs were compared to passive signs. Dynamic signs were shown to be significantly different and better than passive signs, as far as vehicle lateral placement was concerned. The mean of vehicle lateral placement reduction associated with dynamic signs was 0.0875 feet compared to a 0.122 foot mean associated with the passive signs.

The accuracy in collecting vehicle lateral placement data on the highway Driving Simulator could be questioned. The steering mechanism of the HYSIM was not as smooth as on a standard automobile and sometimes resulted in high lateral placement variability. Although the training session provided subjects with a training period to acclimate themselves with the HYSIM features, in most cases the steering control of the vehicle remained a problem.

Validating such data in the field is quite difficult since it would require detector loops at 25-foot intervals for almost 1200 feet and would require an instrumented vehicle.

The literature review indicated that vehicle lateral placement data with respect to traffic signals have not been collected in field studies. Therefore, no general or sound conclusion can be drawn from the results obtained until the data are validated. The results of vehicle lateral placement analysis were inconsistent so that no trend could be followed.

Analysis of AAWS Questionnaire

The AAWS questionnaire data collected in this study consisted of two parts: (1) questions based on driver experience in the driving simulator, and (2) questions based on real-life driving experience. The AAWS questionnaire was designed to draw interferences on driver preferences relative to AAWS. Each of the 60 subject drivers filled out the AAWS questionnaire following the driving simulation test. The AAWS questionnaire form is presented in Appendix C.

Over 80 percent of subject drivers tested on the HYSIM indicated that the AAWS seen in the driving simulation test were helpful in alerting them to upcoming signalized intersections. A graphical summary of subjects' perception of the effectiveness of active advance warning signs in shown in Figure 11. Although this question was designed to get inferences on five categories as shown in Appendix C, presentation of results in Figure 11 was slightly different since drivers' input concentrated on only three categories. Changing the final form in Figure 11 did not affect the outcomes and conclusions.

Drivers who thought the AAWS were helpful commented through personal conversation that the AAWS helped them mentally and physically to stop if needed. Only two percent of total subjects did not like the AAWS; driver unfamiliarity with AAWS was thought to be a contributing factor. In general, more male than female drivers indicated the AAWS were helpful, however, the difference was not significant.

In the driving simulation test, AAWS were placed on a high-speed roadway (45 and/or 55 mph speed limit) to alert drivers to hidden or unexpected signalized intersections. Therefore, positive expectancy of a traffic signal following an AAWS was anticipated to be an important result of this study. Drivers were asked whether they expected the red indication to be illuminated following a flashing AAWS. Over 62 percent of all subjects indicated their positive expectancy. The remaining 38 percent could not relate to the AAWS and thus failed to expect an upcoming traffic signal. Approximately 50 percent of the subjects who did not expect to see a red signal following an AAWS were classified as male/female groups older than 50 years of age. A graphical presentation of the red indication expectancy, classified by sex and age, is shown in Figure 12. Male groups I and II had a greater expectancy compared to female groups. In general, female group III had the lowest expectancy of a red signal indication following an AAWS. Almost one third of the 38 percent of subjects who reported negative expectancy were represented by female group III. Besides the AAWS, the female group III seemed to have the least understanding of highway signs in general. This fact was evident from several hazardous maneuvers that occurred during the driving simulation test. In comparison, the response of the same male group was significantly different from the female group III.

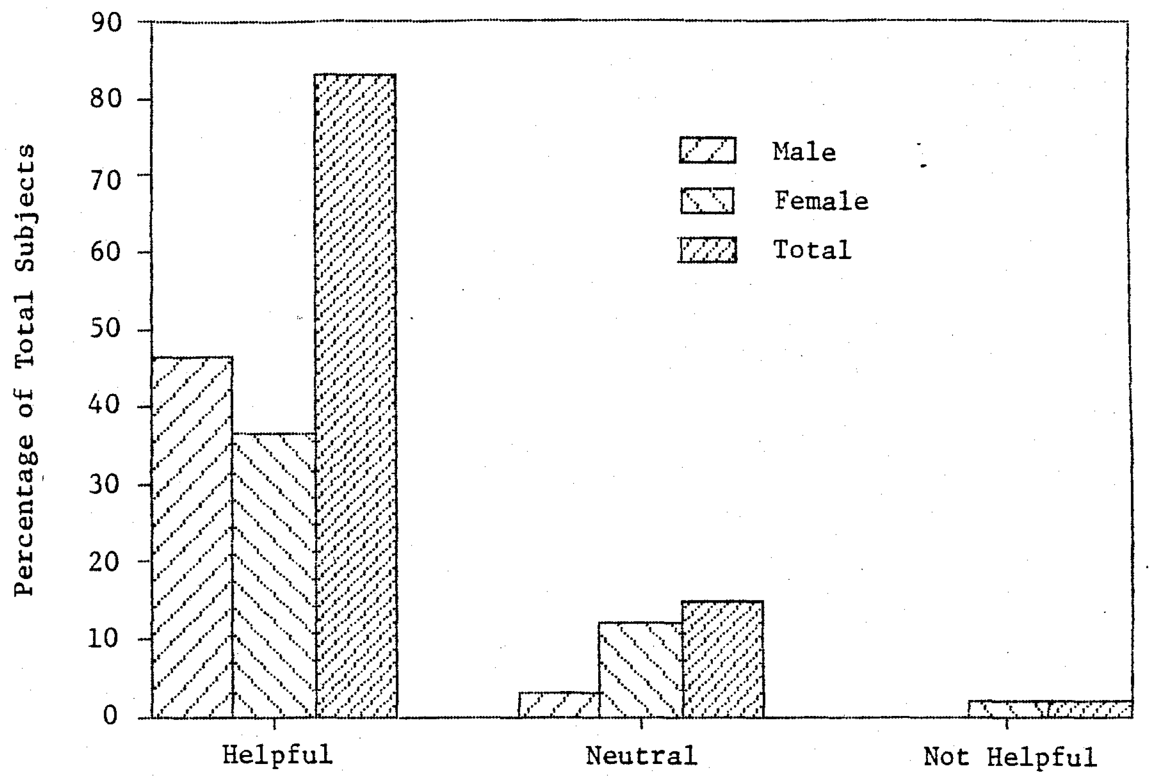


Figure 11. Effectiveness of Active Advance Warning Signs as Perceived by Subject Drivers.

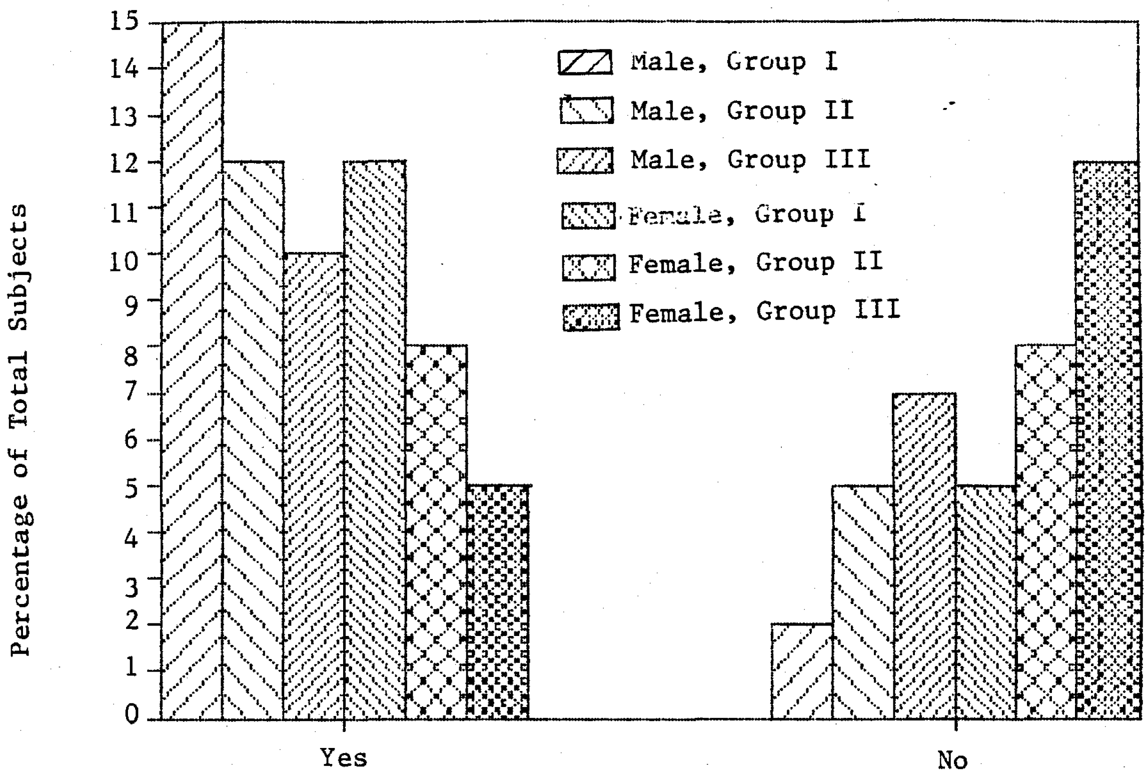


Figure 12. Red Indication Expectancy Following a Flashing Active Advance Warning Sign.

Perhaps some of the subjects did not relate to the AAWS because the sign message was too long or the sign symbol was not legible. This issue was examined further; results are shown in Figure 13. Over 70 percent of subject drivers indicated that all AAWS were legible and simple to comprehend. However, 27 percent of all subjects reported negative responses to some of the AAWS, most notably, the PREPARE TO STOP WHEN FLASHING sings. Approximately 15 percent of those subjects, who could not read the sign message and comprehend it correctly before they passed the signs, were classified as male/female subjects older than 50 years of age. Because older people have slower reading rate and weaker visual acuity than younger people, it was difficult for them to read the PREPARE TO STOP WHEN FLASHING signs without almost stopping to do so. Several of these subjects felt irritation and frustration relative to this particular sign because the word message was too long. Apparently, sex and age differences contributed to this problem. Younger people reported similar responses to the AAWS regardless of sex.

Subject drivers responded properly and were generally pleased when the flashing symbolic signal ahead and the flashing "RED" SIGNAL AHEAD sings were depicted; however, they were dissatisfied with the other AAWS.

The AAWS shown in the driving simulation test were mounted both overhead and on the side of the roadway. In completing the questionnaire, subjects were given the opportunity to select their preferences relative to AAWS location. A graphical summary of driver preferences in AAWS location is shown in Figure 14.

Approximately 50 percent of total subjects preferred side-of-road signs. A smaller percentage of drivers expressed their preference for overhead signs. Generally, driver background and experience were the deciding factors. For example, drivers who had a great deal of experience of freeways and expressways preferred overhead signs. Drivers with much of their experience in city and rural driving preferred ground-mounted signs. Subject drivers commented that ground-mounted signs have better expectancy, especially on two-lane or four-lane divided/undivided roadways. However, there was unanimous agreement that overhead signs should always be considered on highways with four (or more) lane divided/undivided roadways. The same trend was found for ground-mounted signs on two-lane divided/undivided highways. It was also pointed out by subjects that a high frequency of truck traffic would increase demand for overhead signs. As far as the sex effect on this issued, more male groups preferred side of road signs. However, in most cases, male groups agreed on either location. Generally, driver preferences were expressed in terms of sign expectancy, line of sight, adequate illumination, cone of vision and sign legibility. Many subjects commented that location of signs is not significant as long as the sign can be seen and read quickly so that proper action can be taken.

Among all AAWS, the subject drivers first preference was the flashing symbolic signal ahead sing. Approximately 70 percent of subject drivers preferred this sign, probably because it takes less time to comprehend. The signal head symbol on the sign also gives an early warning message of the upcoming traffic signal. A graphical presentation of drivers' first preference in AAWS is shown in Figure 15.

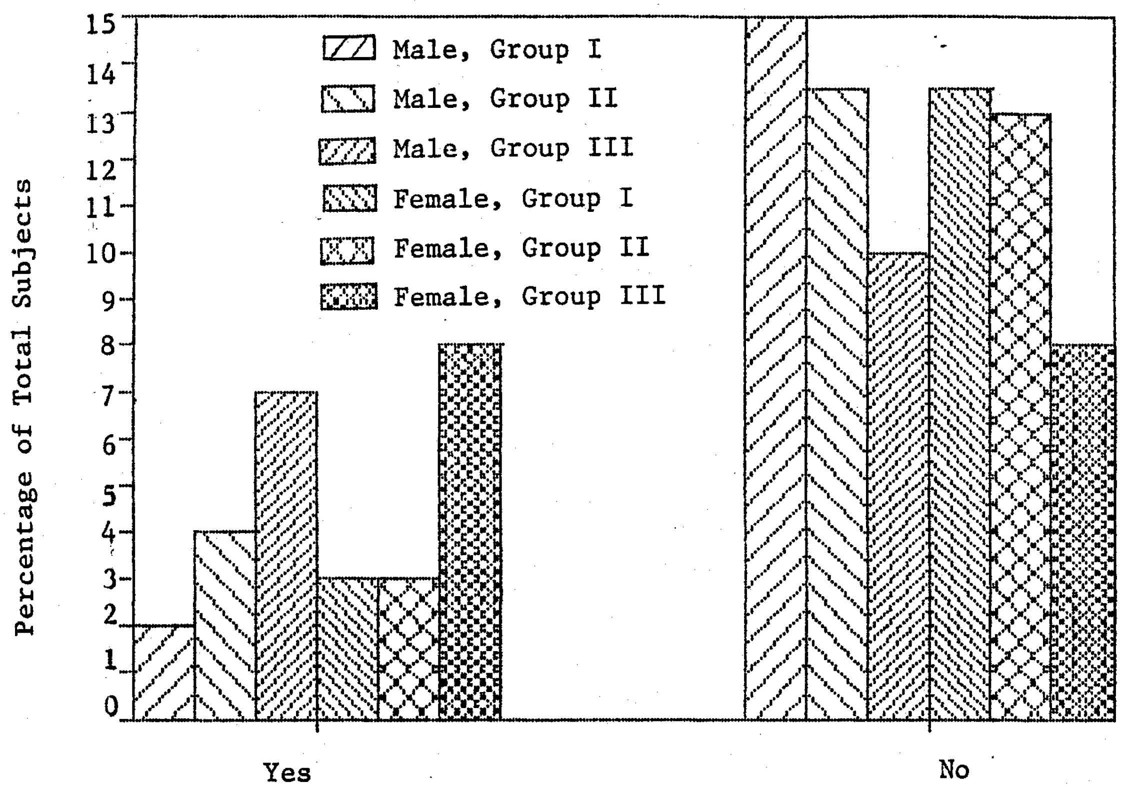


Figure 13. Summary of Driver Responses, By Age and Sex, to Question -- "Were The AAWS Messages Too Long?"

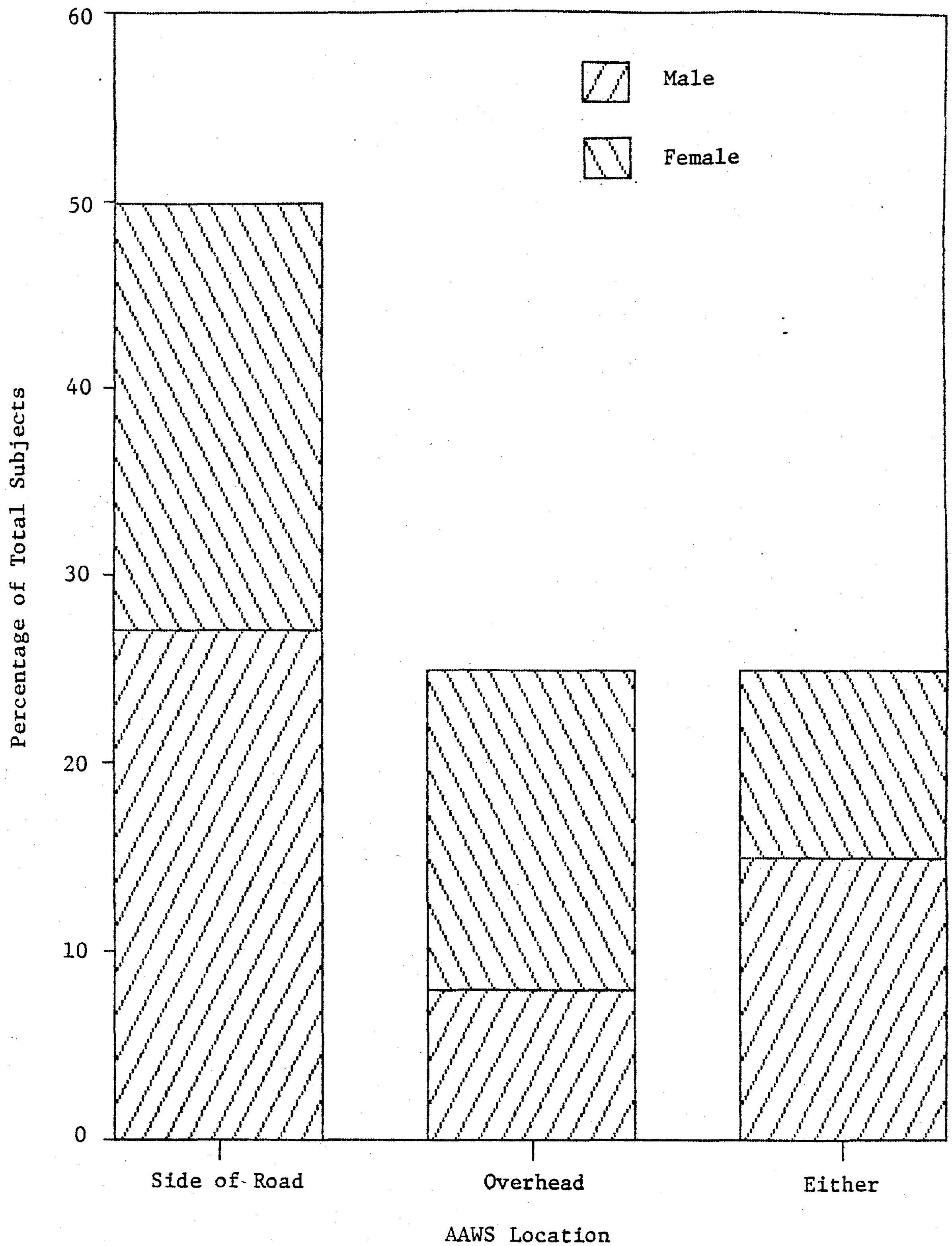


Figure 14. Driver Preferences in AAWS Location.

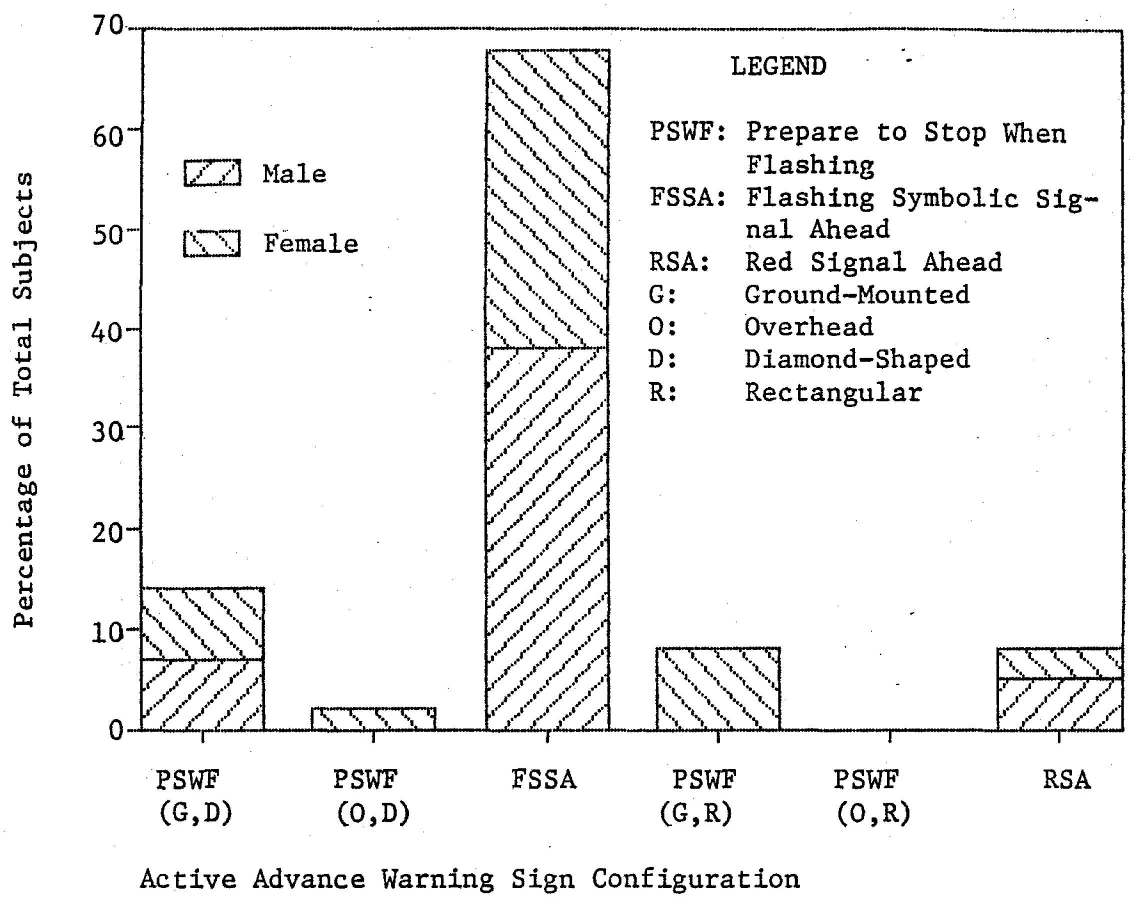


Figure 15. Drivers' First Preference in Active Advance Warning Signs.

The least preferred sign was the rectangular PREPARE TO STOP WHEN FLASHING sign. As mentioned earlier, the PREPARE TO STOP WHEN FLASHING signs were not favorably perceived by subjects because of the confusion about the sign message, its length, its clarity and its purpose. Very few subjects thought the sign related to a traffic signal. Most of the subjects related the PREPARE TO STOP WHEN FLASHING signs to construction zones, stop signs, and/or serious traffic accident in the vicinity. Only a limited number of subjects had any prior experience with the PREPARE TO STOP WHEN FLASHING signs. The flashing symbolic signal ahead sign, however, was indicated to be a very common sign and had been seen frequently around the country.

Other AAWS received negligible citation as first preference. Specifically, the overhead rectangular PREPARE TO STOP WHEN FLASHING did not receive any citation at all. The same non-significance in drivers' first preference in AAWS applied to all other signs except the flashing symbolic signal ahead signs.

Drivers' second preference in AAWS, as shown in Figure 16, was the flashing "RED" SIGNAL AHEAD sign. Although few states recommend the use of this sign, subjects seemed to relate to the sign with no expectancy problems. As a matter of fact, this sign was selected by more than 50 percent of subject drivers, as far as their second preference. As shown in Figure 16, there is enough evidence to support the significance of this sign, as far as the subject drivers' second preference; however, the same sign received negligible citation relative to drivers' first preference. Other AAWS did not receive any noteworthy results.

Subject drivers were given a chance to propose their own signs which they thought might help drivers more than the AAWS seen in the simulator. Very few signs were proposed; a summary of these signs is shown in Figure 17. At least three subject drivers proposed locating the flashing symbolic signal ahead sign on the side of the roadway, while two others indicating that a flashing, ground-mounted, SIGNAL AHEAD sign could be as effective as any of those seen in the simulator. One subject proposed that the flashers (beacons) be placed inside the sign panel, similar to the school zone speed limit signs.

Conversations with the test subjects following the driving simulation test revealed some interesting points. In most cases, subject drivers had only a limited understanding of the purpose of AAWS. In other words, most subjects thought that the AAWS were continuously flashing, regardless of the signal indication. Subjects were somewhat surprised when informed of how AAWS actually worked. A majority of the subject drivers thought the word "active" related to the working mechanism of the sign. This lack of knowledge on AAWS seemed to confuse subject drivers every time an AAWS was depicted. Several subject drivers commented that it was hard to tell whether the sign was active or whether it was continuously flashing. This issue is very important, especially at unfamiliar locations. Therefore, driver confusion could have been a factor in their dislike for these signs.

Information requested on the second part of the AAWS questionnaire was associated with driving experience in real-life conditions. Specifically, subjects were asked what type of response they would usually anticipate when they see an active advance warning sign. In addition to the above, drivers were asked to report their usual response when observing a traffic signal turning from green to yellow.

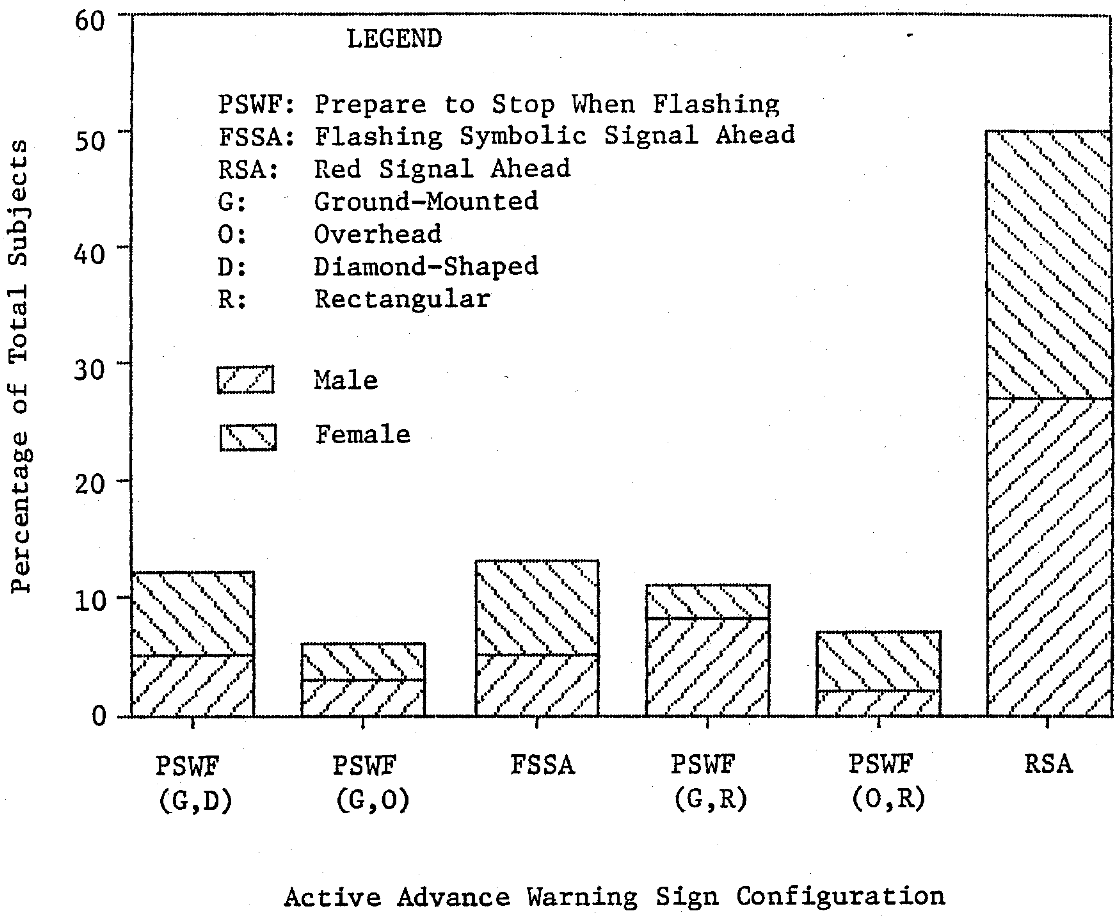
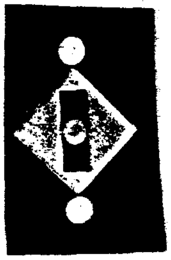
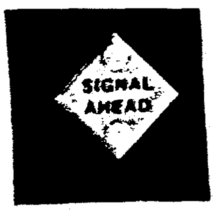


Figure 16. Drivers' Second Preference in Active Advance Warning Signs.



Ground-Mounted Flashing Symbolic Signal Ahead Sign



Ground-Mounted Flashing "SIGNAL AHEAD" Sign

Ground-Mounted or Overhead Flashing "SIGNAL AHEAD" Sign

Figure 17. Summary of Active Advance Warning Signs Proposed by Subject Drivers.

Although subject drivers were confused by the active/continuous issue, approximately 57 percent of subject drivers indicated that after observing an AAWS, they maintained speed but were alerted for stopped traffic or red lights. Forty percent of subject drivers indicated that they normally slowed down immediately if an AAWS was seen. Although such a response depends very much on road geometrics, environmental characteristics, and vehicle approach speed, the questionnaire provided a general idea on how well typical drivers respond under normal and unpressured circumstances. Many drivers felt that travel distance and approach speed to signalized intersection can be major deciding factors on whether drivers should stop on yellow or proceed into the intersection. Sixty-three percent of subject drivers reported that a decision to go through signalized intersections may depend on their perception of distance away from intersections. Thus, drivers would have less tendency to stop if they are very close to an intersection and would have more tendency to stop if they are far from an intersection. A majority of subjects older than 50 years of age (21 percent) indicated their willingness to stop every time the traffic signal turns yellow. Almost none of the subjects indicated any desire to enter the intersection before it turns red. However, this may not be true in real-life driving conditions.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The foregoing investigation of driver responses to and references in Active Advance Warning Signs (AAWS) involved a wide variety of topics. Portions of the project included formulation of an experimental design, using computer software to prepare images of the AAWS, developing the necessary hardware and software for the simulator, and running simulated driving sessions with the test subjects. Because of the comprehensive nature of the research effort, a large number of conclusions have been drawn and recommendations made regarding Active Advance Warning Devices. For organization purposes, conclusions and recommendations will be treated separately.

Conclusions

The main objective of the laboratory study has been accomplished in that data were collected on the HYSIM to observe and evaluate driver response to AAWS of high-speed signalized intersections. Simulator driving sessions were administered to (1) examine driver responses to and preferences in AAWS, (2) examine the effect of sing message length on driver reaction to the sign and (3) determine the most effective position of the warning sign, i.e., overhead or ground-mounted.

Fortunately, a current study to validate the HYSIM has been completed of the Federal Highway Administration Turner-Fairbank Research Center in McLean, Virginia. Several measures of effectiveness were validated, including recognition distance, reaction time, vehicle speed, and several others; validation results were presented positively. Thus, the data collected in this laboratory study represent valid outcomes and driver response to and preference in AAWS were well represented by the measures of effectiveness selected for this experimental study.

As opposed to a field study of a similar nature, this laboratory study was administered with no danger to life and property. It was fairly simple to establish and maintain the experimental controls necessary for valid results. The HYSIM demonstrated its important advantages, especially the economic aspect. Conservatively, it was estimated that a similar field study would have cost more than five times the amount of funds put into this research effort. This does not include the time limitations, liability aspect and other constraints associated with fields studies. Therefore, the HYSIM can be a useful and cost-effective way of doing these types of studies, i.e., human factors application to selecting traffic control devices.

The measures of effectiveness selected for this study were all found to be appropriate. Driver responses to and preferences for AAWS were effectively measured with the selected measures of effectiveness.

The experimental design stage of this investigation received a considerable attention in order to obtain the best measures for driver responses to and preferences in AAWS.

The study demonstrated driver responses to and preferences in eight advance warning signs; two passive and six AAWS. The Flashing Symbolic Signal Ahead (FSSA) sign was shown to be significantly different from and better than all other tested signs. Note that the results of this study are applicable only to night-time driving conditions, since subject drivers on the HYSIM were only exposes to night-time driving.

Driver responses to AAWS were significantly different from and better than their responses to passive signs. In general, driver reaction time to the yellow indication, following a green interval, was significantly shorter when preceded by an AAWS, than when preceded by a passive sign.

The flashing symbolic signal ahead sign was shown to be the most desirable sign by subject drivers, followed by the "RED' SIGNAL AHEAD sign. The flashing symbolic signal ahead sign was shown to reduce vehicle approach speed significantly and better than any other tested flashing sign; this sign was identified much earlier than the other tested signs.

The PREPARE TO STOP WHEN FLASHING sign confused subject drivers rather than helped them to modify their reaction; the sign's message and its length increased driver reaction time. The PREPARE TO STOP WHEN FLASHING sign was the most incorrectly identified sign. Driver preferences for the "PREPARE TO STOP WHEN FLASHING" signs were in general, the least desirable among the signs.

Sign location, i.e., overhead versus ground mounted, was not shown to be a significant factor affecting driver response. However, in the vehicle lateral placement data, the ground-mounted sings caused a significantly greater lane deviation than the overhead signs.

The passive symbolic signal ahead sign was shown to be significantly better than the passive word message "SIGNAL AHEAD" sign. Subject drivers, in general, identified symbolic signs much earlier than the word message signs.

The conclusions drawn from this laboratory study supported the hypothesis that AAWS, are significantly better than passive signs in alerting drivers to high speed signalized intersections. Of these active signs, the flashing symbolic signal ahead signs was shown to have the earliest identification, and it reduced vehicle approach speeds considerably.

Recommendations

Despite the HYSIM's credibility and capabilities, the HYSIM suffers from the lack of visual display creation of the driving environments. It was not quite obvious how much such deficiencies could have affected the final results, in terms of driver responses to and preferences in AAWS of high speed signalized intersections. Although the study examined night-time driving solely, drivers could only see very little of the environmental display in real life condition when driving at night. Nevertheless, it is further recommended that these variables, i.e., display and cues of the driving environments, should be examined in future field and research studies if applicable. Further examination of this issue should not be limited to night-time driving condition but also should consider day time conditions. To do this, it is recommended that a wider field of vision be provided in a two dimensional system, since limited peripheral vision means that subjects, especially elderly ones, are susceptible to motion sickness. In similar laboratory studies, it is recommended that a non-fixed base simulator be used so that subject drivers can encounter the degree of freedom that is maintained in real-life driving conditions. Because of the importance of these issues, the most recent driving simulators, i.e., the German Mercedes Benz and the Swedish Saab driving simulators are now equipped with hardware devices that maintain several degrees of freedom as well as provide a wider field of view. These fine additions would increase in the Highway Driving Simulators credibility as well as their capabilities to simulate realistic scenario sessions.

The study indicated that the flashing symbolic signal ahead sign was the most desirable sign from an operational point of view as well as from drivers preference point of view. This particular sign has been shown to be very effective in alerting drivers to upcoming traffic signals. Therefore, an application standard is needed to define the use, design, installation, and timing criteria for the flashing Symbolic Signal Ahead sign. However, before this step is done, a field study should be conducted to examine the influence of variables such as traffic volume, approach speed, approach geometry and land use on the flashing Symbolic Signal Ahead sign.

Future field studies should examine the effectiveness of the flashing versus passive Symbolic Signal Ahead sign. A benefit-cost (B/C) approach would be desirable based on accident data collected at several sites around the country. At least two years of before/after accident data must be available for access the B/C ration method. Such as study could provide information on when to use AAWS as apposed to passive signs.

Although the MUTCD stated that the word message "SIGNAL AHEAD" can be substituted for the Symbolic Signal Ahead sign, this laboratory study showed that the "SIGNAL AHEAD" sign was not nearly as effective as the Symbolic Signal Ahead sign. Therefore, it is recommended that consideration be given to revising this part of the MUTCD.

For future field or laboratory studies, it is recommended that the Flashing and the Passive Symbolic Signal Ahead signs be tested at locations similar to the ones tested on the HYSIM. However, unlike the HYSIM, day time as well as night time. Data must be collected to establish a base for solid conclusions.

Due to the nature of this study and its practicality at high-speed signalized intersections, it is recommended that only when conventional counter-measures fail to solve the problem at high-speed signalized intersections should agencies consider the use of AAWS are used, they should be installed very selectively so that their effectiveness is not diminished by overuse.

Because drivers commented that the PREPARE TO STOP WHEN FLASHING signs have very limited and inadequate relationship to traffic control signals, practicing traffic engineers should not use these signs of high-speed signalized intersections as advance warning signs to traffic signals. Practicing traffic engineers should be aware of drivers preference in AAWS, otherwise these signs can no longer serve their purpose and thus result in unnecessary spending of funds, not to mention accident occurrence as a result of driver miscomprehension and failure to observe signs.

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APPENDIX A

HIGHWAY SIMULATOR EXPERIMENT DESCRIPTION

Driving the highway simulator is very much like driving a real car. You will sit behind the wheel of a Ford Fairmont, looking down the roadway which is displayed on a large screen in front of you. When you step on the gas, you will hear the engine revving and changing rpm as the 3-speed automatic transmission shifts through each gear. As you drive along the road, you will hear the air rushing by your window and the sound of your tires rolling along the pavement. If you should try to stop or change lanes too quickly, your tires will squeal as they lose traction. If you get too far out of your lane, you will have an accident, indicated by a crashing sound.

Along the road you will pass various highway signs and traffic signals. Some of these signs will require actions on your part (e.g., slowing down for a hidden intersection, slowing down for a speed zone, and turning to follow a specific route). The traffic signal lights may change requiring you to make a decision to stop or go through the intersection.

You will be asked to drive the simulator for a 10-15 minute training session till you become comfortable and used to driving the simulator. The training session is to allow you to acclimate yourself with the simulator display, steering control, crash simulation (potential accident), police siren (violating speed limit and red lights), and to familiarize you with the vehicle acceleration and brake application. After acclimating yourself with the simulator, you will be asked to drive a scenario which has been laid out especially for this experiment.

On the scenario/course, signs will be presented under clear visibility conditions; in this course, you will drive along four-lane divided or undivided highways, on a dark night illuminated only by your headlights.

The scenario/course is dotted with signs of three types:

- Warning signs, which tell you of potentially hazardous driving conditions or traffic signals ahead,
- Regulatory signs, which restrict your behavior in some way, and
- Guide signs, which give you information and direction unrelated to driving conditions.

Speed limit signs are regulatory and are enforced by "cops" located at various points in the course. If you exceed the speed limit (by more than five miles-per-hour) and a cop is in the vicinity, you will hear a siren which tells you that you have been caught for speeding by a cop. Reducing your speed below the speed limit will turn the siren off and allow you to continue along the course. Other signs, such as warning signs, are to alert you of approaching conditions such as traffic signals or sharp curves hidden by road side features. During the driving scenario, you will see some intersections equipped with traffic lights (signalized); you are advised to react and respond properly to traffic signals, just as if you were faced by traffic signals in real-world driving conditions.

One of the things we are testing in this experiment is how well signs can be recognized on the simulator; other findings are driver responses and preferences to signs on the simulator. For this reason, the operation of the headlight dimmer switch on the Ford Fairmont car has been modified. In certain cases you will be asked to operate the dimmer switch, by pulling the headlight stalk toward you until it clicks and then releasing it. During the training session you will be trained to activate the headlight stalk. However, you are advised at all times to have your left hand on the steering wheel and close to the headlight stalk so that you can activate the headlight stalk rapidly when needed. During the test on the simulator you will be asked and required to activate the headlight stalk every time you identify a sign that warns you of an oncoming traffic signal. Failure to identify the correct sign by activating the stalk for the wrong sign, or failure to activate the headlight stalk for the correct sign, will result in $1.00 deduction of your bonus.

It is advised that you drive the course as fast as possible without breaking the law or having an accident. To encourage you to do so, we have established a scheme of rewards and penalties. You will receive a fixed amount of money for finishing the driving task through the course. However, completing the driving sessions with minimal delay and without any tickets or crashes can increase your bonus. Also, identifying the signs correctly and completing the follow-up questionnaire would increase the amount of bonus. Your bonus can also be reduced if you drive carelessly or fail to pay close attention to the signs.

During the driving mission, should you have any problem (motion sickness..., etc.) or need to ask a question, please speak in a normal voice which will be heard by the person at the simulator control console. Conversation can be made by means of a two-way intercom system. The microphone which picks up your voice will be attached to your shirt. Route direction and map instructions will be given to you in advance of any situation that needs action on your part.

If you have any questions after reading this experimental procedure or before you participate in the experiment, please feel free to ask.

APPENDIX B

Table B-1. Lengths of Speed Zones.

Approach Speed (mph)	Option* Zone (Ft)	Speed Zones (Ft)		
		1	2	3
45	284 - 330	801 - 1200	307 - 800**	0 - 307
55	400 - 404	801 - 1200	400 - 800	0 - 400

* Option zones are based on 5-second change interval and 10-ft/sec^2 deceleration rate (10).

** Active warning signs are placed 800 ft in advance of high-speed signalized intersections.

APPENDIX C

ACTIVE ADVANCE WARNING SIGNS (AAWS) QUESTIONNAIRE

This questionnaire consists of two parts: Part I relates to what you saw on the driving simulator, and Part II relates to your driving experience in real life conditions.

Part I: (relates to driving on the simulator)

(1) Do you feel the Active Warning signs like the "PREPARE TO STOP WHEN FLASHING" or the flashing "RED" SIGNAL AHEAD sign you saw during the driving simulation tests alerted you to the fact that you were approaching an intersection with a traffic signal and prepared you to stop if necessary? Please mark an "X" along the line below at or near the descriptor that best describes your feelings.

|______|______|______|______|

very helpful	helpful	neutral	unhelpful	not helpful at all

(2) When you saw the flashing lights or the "Red" message flashing, did you expect the traffic signal to be red before you got to the intersection? Please circle the appropriate answer.

YES/NO

Comments, ____

____

QUESTIONNAIRE DATA (Cont'd.)

(3) Were any of the sign messages so long that you could not completely read the message before you passed the sign? Check the appropriate answer. (In this question, please refer to question #5 to refresh your memory about the signs.)

______ yes

______ no

If yes, please indicate which sign or signs you could not read by listing the appropriate letter, e.g., (a), (b), ---------- or (f) from question #5.

____

____

(4) During the driving simulation test you saw, some of the Active Warning signs were mounted along side the road while others were above the road. At which location would you rather see the signs on highways? Please check the appropriate answer and state why in the space below.

______ side of road

______ overhead

______ either one

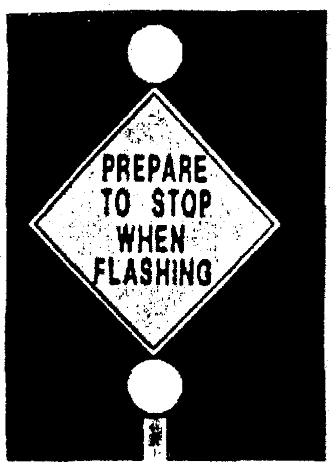
Comments, ______________________________________

____

QUESTIONNAIRE DATA (Cont'd.)

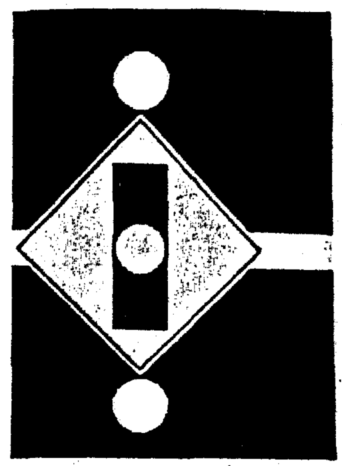
(5) The signs shown are the same as those seen during the driving simulation test. Which two do you prefer most? (Put letter in appropriate box.)

[ ] first preference [ ] second preference

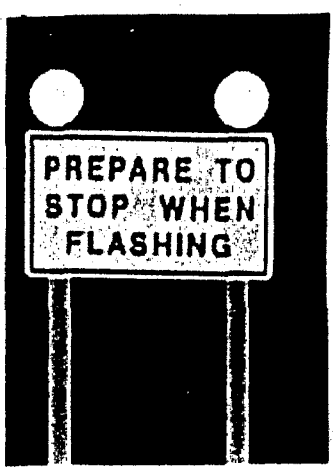


Side of Road
(a)

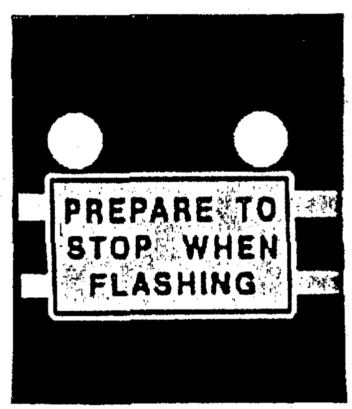
Overhead
(b)



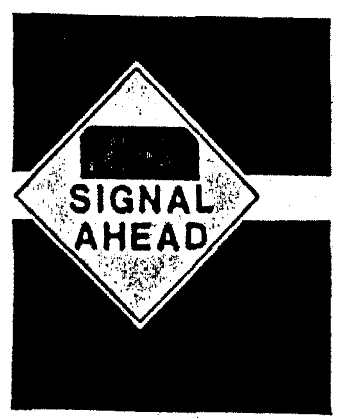
Overhead
(c)



Side of Road
(d)



Overhead
(e)



Overhead
(f)

QUESTIONNAIRE DATA (Cont'd.)

(6) If you did not think the active warning signs shown in the simulator were helpful to alerting you, please propose one sign with either word or symbolic message that you feel is better than those shown in question #5. (Sketch sign in the box below.)

Part II: (This relates to your driving experience in real life conditions.)

(7) When you see active warning signs, do you normally slow down or maintain your speed before you see the actual traffic signal itself?

______ Slow down immediately.

______ Maintain speed but alerted for stopped traffic or red lights.

______ Maintain speed until I see traffic light.

______ Other. (Comments), ______________________________

(8) When the traffic signal turns yellow, do you usually try to stop or do you speed up to try and make it through the intersection before it turns red? Check the appropriate answer.

______ Try to stop.

______ Try to enter the intersection before it turns red.

______ Depends on how close I am to the intersection.

______ Other. (Comments), ______________________________

SYSTEM EVALUATION QUESTIONNAIRE

Please mark an "X" along the line below at or near the descriptor that best describes your feelings. For example:

1. The simimulator is a very large device.

very large	X large	normal	small	very small

2. My sensation of speed in the simulator when compared to actual night driving can be summarized as follows:

simulator speed much lower	simulator speed seems lower	about the same	simulator speed seems higher	simulator speed much higher

3. During the trip I felt:

very comfortable	comfortable	neither comfortable nor uncomfortable	mildly uncomfortable	very uncomfortable

4. Compared to night driving on actual roads, the simulator seems:

very realistic	realistic	no opinion	artificial	very artificial

5. The legibility of the signs may be described as:

very good	good	okay	poor	very poor

6. Simulation of roads and intersections on the simulator compared to actual roads and intersections can be summarized as follows:

very realistic	realistic	no opinion	artificial	very artificial

7. When I steer the car, it seemed:

much too responsive	too responsive	about right	sluggish	very sluggish

8. When I step on the brake, stopping seemed:

much too abrupt	too abrupt	about right	sluggish	very sluggish

9. Overall I found the simulator trip to be:

very taxing	taxing	about right	boring	very boring

10. My willingness to participate in another simulator study can be described as follows:

very eager to start	probably so	not sure	probably not	never again

11. The instructions which I received were:

very difficult to understand	difficult to understand	okay	easy to understand	very easy to understand

12. Compared to the first half of the trip, I felt during the second half:

much more comfortable	more comfortable	about the same	less comfortable	much less comfortable

APPENDIX D

Table D-1. Sample Size Determination Procedure.

STEP	PROCEDURE
1	Run pilot test with sample size n' (n' is a reasonable guess).
2	Code data (Measures of Effectiveness).
3	Calculate and tabulate ANOVA results.
4	Select mean squares (MS), as appropriate; apply appropriate models.
5	Set Type I error (α) as appropriate
6	Choose power ($1-\beta$) as appropriate
7	Calculate degree of freedom of denominator as follows: $DF_{denom.} = a(n-1)$ where a = no. of treatments in a given factor; n = actual sample size per cell.
8	Refer to Figure D-1; read non-centrality parameter, ϕa.
9	Calculate Σ (dev.)^2 as follows: $\Sigma \text{ (dev. between means)}^2 = \frac{\phi_a{}^2 \cdot MS \cdot a}{n}$
10	Determine whether Σ (dev.)^2 between means is acceptable; if not repeat steps 5 through 9 by either changing n, power of the experiment ($1-\beta$), or Type II error (α).

Table D-2. Values of ϕ_a^2 Effect in AxB Design Both Factors Fixed.(11)

Source	$\Sigma(\text{dev.})^2$	Est. Observa.	α^2 effect
A	$\frac{(a-1)}{bs}$ $[MS_A - MS_{s/AB})]$	bs'	$\frac{bs' \; [\Sigma(\mu i-\mu)^2]/a}{MS_{s/AB}}$
B	$\frac{(b-1)}{as}$ $[(MS_B - MS_{s/AB})]$	as'	$\frac{as' \; [\Sigma(\mu j \mu)^2]/b}{MS_{s/AB}}$
AxB	$\frac{(a-1)(b-1)}{s}$ $[(MS_B - MS_{s/AB})]$	s	$\frac{s'[\Sigma(\mu i-\mu)(\mu j-\mu)]^2/ \; [(a-1)(b-1)+1]}{MS_{s/AB}}$

μi = Population treatment mean of hte ith treatment; i=1,....8.
μj = Population treatment mean of the jth treatment; j=1,2.
μ = Overall population mean.
a = No. of treatments in Factor A.
b = No. of treatments in Factor B.
s' = Sample size tried in an attempt to find a value producing the desired level of power.
s = Sample size in thepilot experiemtn
ϕa = Noncentrality parameter.
MS_a = Mean of squares in factor A.
MS_b = Mean of squares in factor B.
MS_{AB} = Mean of squares in both interacted factors AxB.
$MS_{S/AB}$ = Error Term (Subject within AB-Mean Squares Error).

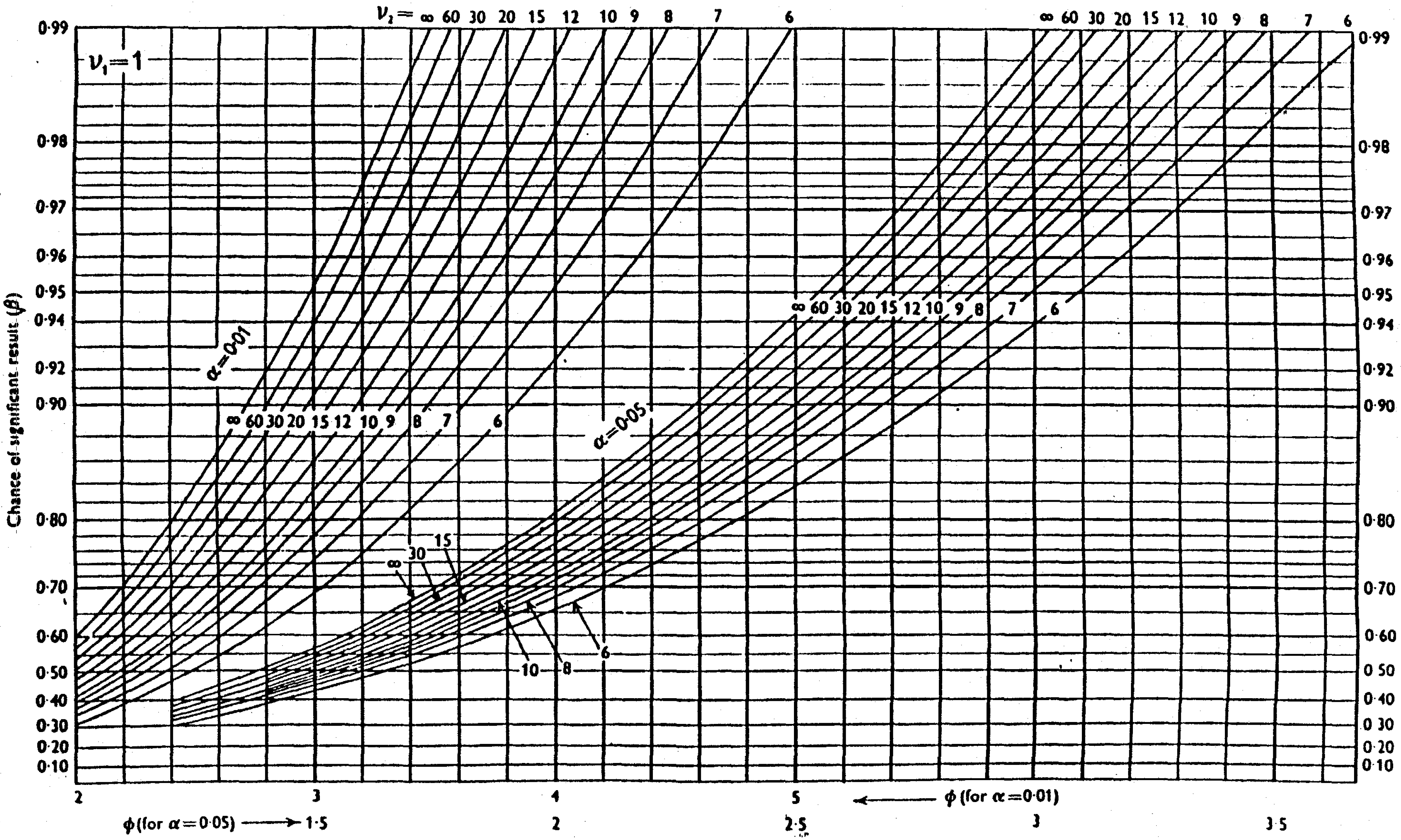


Figure D-1. Charts of the Power Function For Analysis of Variance Test (Keppel, 1973). (11)

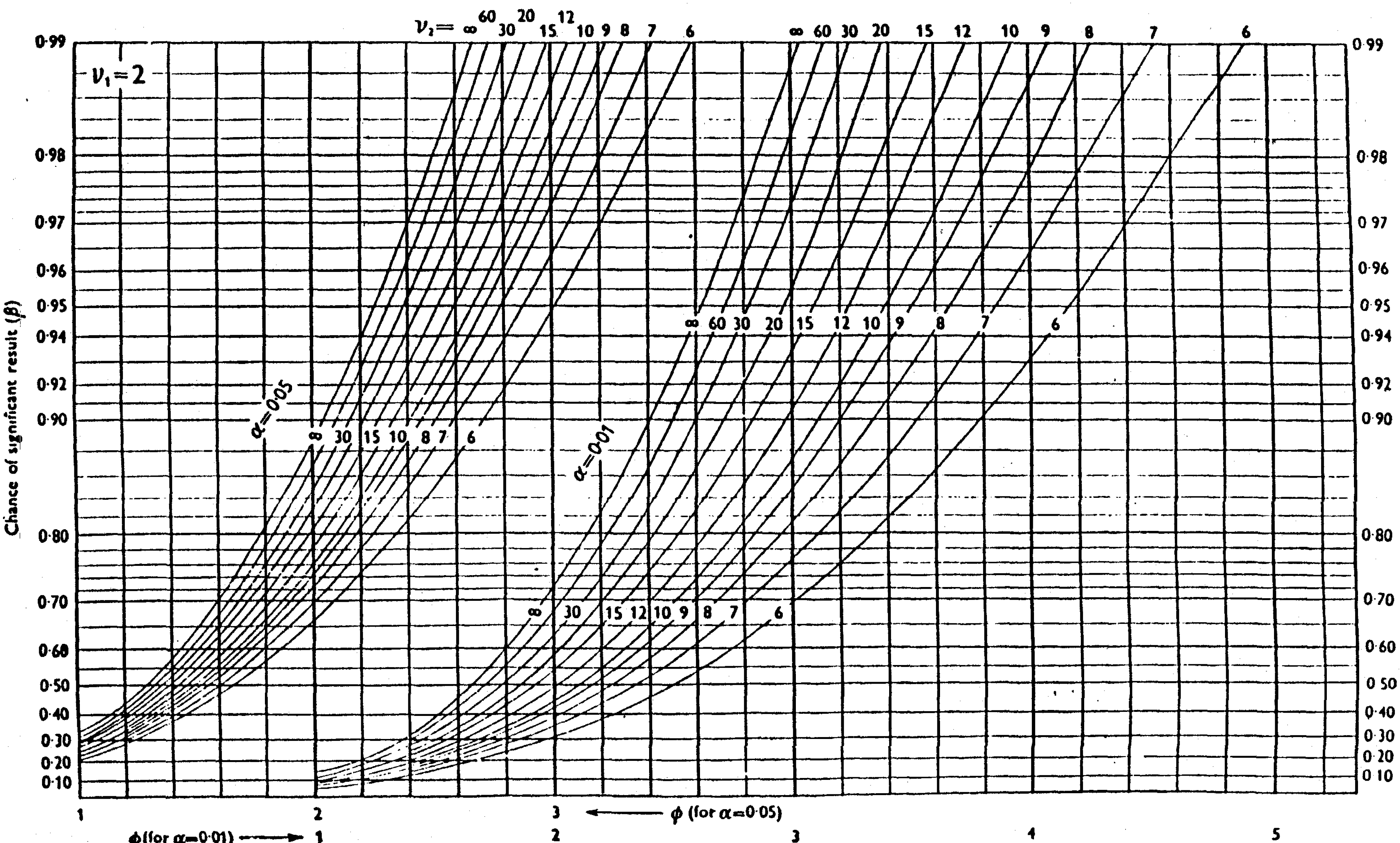


Figure D-1. (Continued)

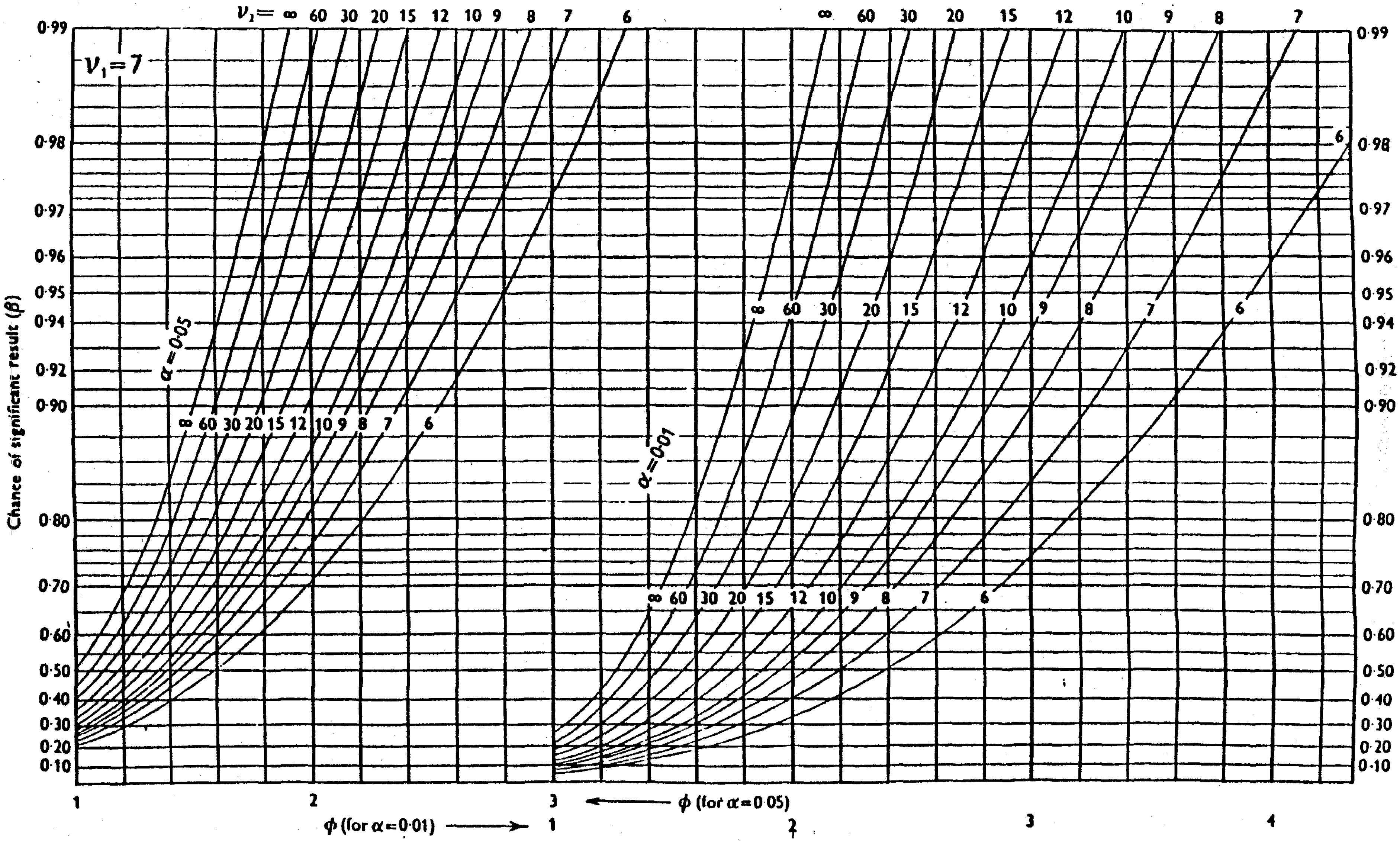


Figure D-1. (Continued)

APPENDIX E

RECORD OF INFORMED CONSENT

Part 46, Subtitle A of Title 45 of the Code of Federal Regulations, relating to the Protection of Human Subjects in research, requires your informed consent for participation in Federal Highway Administration (FHWA) Driving Studies. Section 46.103(c) gives the following definition: "Informed consent means the knowing consent of an individual or his legally authorized representative, so situated as to be able to exercise free power of choice, without undue inducement or any element of force, fraud, deceit, duress, or other form of constraint."

1. You will be asked to present a valid drivers license in order to participate in the simulation study. You will then be asked for a minimal amount of biographical information necessary to the study. All information provided is confidential, and your name will not be disclosed to the public. A short practice session will be provided in order to familiarize you with the driving simulator. When you feel that you are ready, you may continue to the actual simulation. You will be driving a simulated trip made especially for this experiment. After leaving the simulator, you will be asked to complete the post-test questionnaire. The entire session will take approximately 1 to 1-1/2 hours.

2. Other than possible fatigue due to extended concentration, you should not experience other attendant discomforts and you will not be subjected to risks.

3. Upon completion of the session, you will be paid a minimum of $10 for your participation with the possibility of up to $5 bonus for good driving. You will also be paid $5 for completing the post-test questionnaire.

4. Inquiries you have concerning the procedure will be answered.

5. You are free to decline to consent or withdraw your consent and to discontinue participation in the project at any time. If at any time you feel uncomfortable or unsettled during simulator runs, you should simply indicate your concern and the simulation will be stopped.

The basic elements of information have been presented and understood by me, and I consent to participation as a subject in FHWA's driving simulator.

Name: ______________________________

Signature: ______________________________

Date: ______________________________

BIOGRAPHICAL INFORMATION FORM AND ORTHO-RATER TEST CRITERIA

BIOGRAPHICAL INFORMATION

Name: ____________________

Address: ____________________

City: __________ State: __________ Zip: ______

Phone: __________ Occupation: __________

Age: (Check the appropriate box) __ (16-30 yrs), __ (31-50 yrs), __ (50 yrs)

Sex: __ Male __ Female

VISION

Far Visual Acuity _____ Corrected: ___/___

Near Visual Acuity _____ Corrected: ___/___

Color Vision (Yes or No): __________ (See Key Word #3)

DRIVING EXPERIENCE

Years Driving: ____________________

Average Miles/Week (or Miles/Year): __________

% on Freeway: __________ % in City: __________

Have you ever had any accidents at high-speed (speed limit more than 45 mph) intersections? (Yes or No) __________

If yes, please briefly describe the circumstances of the accident.

____

____

Do you have any vision problems driving at night? (Yes or No) ______

Describe: ____________________

Do you ever have car or motion sickness problems? (Yes or No) ______

Describe: ____________________

Key Word 1: __________ Key Word 3: __________

Key Word 2: __________

Comments: ____________________

ORTHO-RATOR TEST

F1 0 1 2 3 4 5 6 7 8 9 10

F2 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

F3 1 2 3 4 5 6 7 8 9 10 11 12

R ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

NOTE: ____

F6 T A B C D E F G H

____ ____ ____ ____ ____ ____ ____ ____ ____

NOTE: ____

F7 LEFT: ______________ RIGHT: ______________

TOP: ______________ BOTTOM: ______________

NOTE: ____

N1 1 2 3 4 5 6 7 8 9 10 11 12

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

NOTE: ____

SCORING

F3	1	2	3	4	5	6	7	8	9	10	11	12
	R	L	T	L	B	L	T	B	T	R	B	R
F6	T	A	B	C	D	E	F	G	H			
	3	2	4	3	5	4	2	5	4			
N1	1	2	3	4	5	6	7	8	9	10	11	12
	T	T	R	T	R	T	L	T	R	L	R	B

NUMBER	SNELLEN
1	20/200
2	20/100
3	20/67
4	20/50
5	20/40
6	20/33
7	20/29
8	20/25
9	20/22
10	20/20
11	20/18
12	20/17

HYSIM EXPERIMENT

SUBJECT BACKGROUND INFORMATION

Subject ID Number: ____________________

Name: ____________________
(last) (first) (m.i.)

Street Address: ____________________

City: ____________ State: ____________ Zip Code: ________

Phone: ____________________

Age: ______ Sex: ____________

Number of Years Driving: ______

% on Freeway: ____________

% in City: ____________

No. of Accidents at High-Speed Intersections: ____________

Far Visual Acuity: ____________

Near Visual Acuity: ____________

Color Vision: ____________

To Be Filled Out by FHWA

Previous HYSIM Subject? Y/N: ____________________

Experiment: ____________________

Date: ____________________

Time: ____________________

Keyword? Y/N: ____________________

APPENDIX F

Table F-1. Summary of Reward/Penalty Scheme.

Reward (+)*/Penalty (-)**	Event
+ $10.00	Participating in the two-session run.
+ $ 5.00	Completing the questionnaire data: System and Active Advance Warning Signs (AAWS) questionnaires.
+ $ 5.00	Bonus for completing both sessions without delay, no accidents, no tickets for speeding, or running red lights and for identifying signs correctly.
- $ 0.50	Speed violation.
- $ 0.50	Crash (accidents).
- $ 0.25	Delay per minute.
- $ 1.00	Running red light.
- $ 1.00	Misidentification of signs.

* Maximum amount of money subject drivers can make is $20.00.

** Minimum amount of money subject drivers can make if they complete both driving sessions and the questionnaire, regardless of how many penalties they receive, is $15.00.

APPENDIX G

SAMPLES OF DATA COLLECTED DURING SIMULATOR RUNS

Table G-1. Sample of Sign Identification Distance Data

SIGNIDDS	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
312	1	440	0.113	49.661
312.3	1	441	0.113	49.774
312.4	1	442	0.113	49.887
312.5	1	443	0.113	50.000
312.7	1	444	0.113	50.113
313.9	1	445	0.113	50.226
314.2	1	446	0.113	50.339
314.6	2	448	0.226	50.564
316	1	449	0.113	50.677
316.1	1	450	0.113	50.790
316.2	1	451	0.113	50.903
316.8	1	452	0.113	51.016
317.3	1	453	0.113	51.129
318.2	1	454	0.113	51.242
318.5	1	455	0.113	51.354
319.5	1	456	0.113	51.467
319.7	1	457	0.113	51.580
321.6	1	458	0.113	51.693
321.9	1	459	0.113	51.806
323	1	460	0.113	51.919
323.6	1	461	0.113	52.032
323.8	1	462	0.113	52.144
323.9	1	463	0.113	52.257
324.3	1	464	0.113	52.370
324.6	1	465	0.113	52.483
325.4	1	466	0.113	52.596
325.9	1	467	0.113	52.709
326.1	1	468	0.113	52.822
327.8	1	469	0.113	52.935
328	1	470	0.113	53.047
329.1	1	471	0.113	53.160
329.6	1	472	0.113	53.273
329.8	1	473	0.113	53.386
330.9	1	474	0.113	53.499
331.5	1	475	0.113	53.612
331.8	1	476	0.113	53.725
331.9	1	477	0.113	53.837
332.3	1	478	0.113	53.950
333.3	1	479	0.113	54.063
333.6	1	480	0.113	54.176
334.2	1	481	0.113	54.289
334.5	1	482	0.113	54.402
335.2	1	483	0.113	54.515
335.7	1	484	0.113	54.628
335.9	1	485	0.113	54.740
336.2	2	487	0.226	54.966
336.5	1	488	0.113	55.079
337	1	489	0.113	55.192
337.9	1	490	0.113	55.305
338.4	2	492	0.226	55.530
339.1	1	493	0.113	55.643
339.5	1	494	0.113	55.756
339.6	1	495	0.113	55.869
339.7	2	497	0.226	56.095
340.1	1	498	0.113	56.208
340.2	1	499	0.113	56.321
340.4	1	500	0.113	56.433

Table G-2. Sample of Reaction Time Data

REACTME5	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
.	2	.	.	.
0.1	6	6	0.626	0.626
0.2	10	16	1.044	1.670
0.3	7	23	0.731	2.401
0.4	49	72	5.115	7.516
0.5	172	244	17.954	25.470
0.6	85	329	8.873	34.342
0.7	100	429	10.438	44.781
0.8	169	598	17.641	62.422
0.9	55	653	5.741	68.163
1	42	695	4.384	72.547
1.1	69	764	7.203	79.749
1.2	33	797	3.445	83.194
1.3	16	813	1.670	84.864
1.4	32	845	3.340	88.205
1.5	13	858	1.357	89.562
1.6	8	866	0.835	90.397
1.7	18	884	1.879	92.276
1.8	8	892	0.835	93.111
1.9	9	901	0.939	94.050
2	8	909	0.835	94.885
2.1	5	914	0.522	95.407
2.2	1	915	0.104	95.511
2.3	7	922	0.731	96.242
2.4	2	924	0.209	96.451
2.5	2	926	0.209	96.660
2.6	6	932	0.626	97.286
2.7	2	934	0.209	97.495
2.8	5	939	0.522	98.017
2.9	1	940	0.104	98.121
3	1	941	0.104	98.225
3.2	2	943	0.209	98.434
3.5	1	944	0.104	98.539
3.6	2	946	0.209	98.747
3.8	1	947	0.104	98.852
4.1	1	948	0.104	98.956
4.2	2	950	0.209	99.165
4.4	2	952	0.209	99.374
4.6	1	953	0.104	99.478
4.7	1	954	0.104	99.582
4.8	2	956	0.209	99.791
4.9	1	957	0.104	99.896
5	1	958	0.104	100.000

Table G-3. Sample of Vehicle Approach Speeds in Zone 1

V1	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
36.1	2	99	0.208	10.312
36.2	1	100	0.104	10.417
36.3	8	108	0.833	11.250
36.4	2	110	0.208	11.458
36.5	3	113	0.313	11.771
36.6	4	117	0.417	12.187
36.7	2	119	0.208	12.396
36.8	1	120	0.104	12.500
36.9	6	126	0.625	13.125
37.1	5	131	0.521	13.646
37.2	4	135	0.417	14.062
37.3	6	141	0.625	14.687
37.4	1	142	0.104	14.792
37.5	1	143	0.104	14.896
37.6	3	146	0.313	15.208
37.7	4	150	0.417	15.625
37.8	3	153	0.313	15.937
37.9	3	156	0.313	16.250
38	3	159	0.313	16.562
38.1	6	165	0.625	17.187
38.2	5	170	0.521	17.708
38.3	5	175	0.521	18.229
38.4	4	179	0.417	18.646
38.5	2	181	0.208	18.854
38.6	6	187	0.625	19.479
38.7	5	192	0.521	20.000
38.8	5	197	0.521	20.521
38.9	6	203	0.625	21.146
39	8	211	0.833	21.979
39.1	3	214	0.313	22.292
39.2	3	217	0.313	22.604
39.3	6	223	0.625	23.229
39.4	9	232	0.938	24.167
39.5	6	238	0.625	24.792
39.6	7	245	0.729	25.521
39.7	8	253	0.833	26.354
39.8	8	261	0.833	27.187
39.9	8	269	0.833	28.021
40	6	275	0.625	28.646
40.1	6	281	0.625	29.271
40.2	3	284	0.313	29.583
40.3	10	294	1.042	30.625
40.4	6	300	0.625	31.250
40.5	7	307	0.729	31.979
40.6	3	310	0.313	32.292
40.7	5	315	0.521	32.812
40.8	8	323	0.833	33.646
40.9	4	327	0.417	34.062
41	9	336	0.938	35.000
41.1	5	341	0.521	35.521
41.2	9	350	0.938	36.458
41.3	13	363	1.354	37.812
41.4	6	369	0.625	38.437
41.5	2	371	0.208	38.646
41.6	8	379	0.833	39.479
41.7	7	386	0.729	40.208
41.8	13	399	1.354	41.562

Table G-4. Sample of Vehicle Approach Speeds in Zone 2

V2	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
33.8	5	88	0.521	9.167
33.9	3	91	0.313	9.479
34	5	96	0.521	10.000
34.1	2	98	0.208	10.208
34.2	1	99	0.104	10.312
34.3	3	102	0.313	10.625
34.4	1	103	0.104	10.729
34.6	1	104	0.104	10.833
34.7	4	108	0.417	11.250
34.9	2	110	0.208	11.458
35	3	113	0.313	11.771
35.1	3	116	0.313	12.083
35.2	1	117	0.104	12.187
35.3	2	119	0.208	12.396
35.4	1	120	0.104	12.500
35.5	4	124	0.417	12.917
35.6	5	129	0.521	13.437
35.7	2	131	0.208	13.646
35.8	3	134	0.313	13.958
35.9	5	139	0.521	14.479
36	5	144	0.521	15.000
36.1	2	146	0.208	15.208
36.2	6	152	0.625	15.833
36.3	2	154	0.208	16.042
36.4	4	158	0.417	16.458
36.5	2	160	0.208	16.667
36.6	6	166	0.625	17.292
36.7	5	171	0.521	17.812
36.8	4	175	0.417	18.229
36.9	3	178	0.313	18.542
37	2	180	0.208	18.750
37.1	3	183	0.313	19.062
37.2	5	188	0.521	19.583
37.3	2	190	0.208	19.792
37.4	3	193	0.313	20.104
37.5	9	202	0.938	21.042
37.6	4	206	0.417	21.458
37.7	7	213	0.729	22.187
37.8	2	215	0.208	22.396
37.9	7	222	0.729	23.125
38	9	231	0.938	24.062
38.1	13	244	1.354	25.417
38.2	6	250	0.625	26.042
38.3	5	255	0.521	26.562
38.4	3	258	0.313	26.875
38.5	4	262	0.417	27.292
38.6	4	266	0.417	27.708
38.7	6	272	0.625	28.333
38.8	7	279	0.729	29.062
38.9	6	285	0.625	29.687
39	4	289	0.417	30.104
39.1	4	293	0.417	30.521
39.2	11	304	1.146	31.667
39.3	5	309	0.521	32.187
39.4	4	313	0.417	32.604
39.5	3	316	0.313	32.917
39.6	2	318	0.208	33.125

Table G-5. Sample of Vehicle Approach Speed Reduction Data.

V2V1	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
-3.8	7	132	0.729	13.750
-3.7	3	135	0.313	14.062
-3.6	4	139	0.417	14.479
-3.5	4	143	0.417	14.896
-3.4	14	157	1.458	16.354
-3.3	10	167	1.042	17.396
-3.2	2	169	0.208	17.604
-3.1	7	176	0.729	18.333
-3	3	179	0.313	18.646
-2.9	8	187	0.833	19.479
-2.8	5	192	0.521	20.000
-2.7	8	200	0.833	20.833
-2.6	7	207	0.729	21.562
-2.5	10	217	1.042	22.604
-2.4	7	224	0.729	23.333
-2.3	4	228	0.417	23.750
-2.2	6	234	0.625	24.375
-2.1	5	239	0.521	24.896
-2	12	251	1.250	26.146
-1.9	10	261	1.042	27.187
-1.8	11	272	1.146	28.333
-1.7	10	282	1.042	29.375
-1.6	17	299	1.771	31.146
-1.5	17	316	1.771	32.917
-1.4	9	325	0.938	33.854
-1.3	15	340	1.563	35.417
-1.2	23	363	2.396	37.812
-1.1	17	380	1.771	39.583
-1	17	397	1.771	41.354
-0.9	15	412	1.563	42.917
-0.8	17	429	1.771	44.687
-0.7	19	448	1.979	46.667
-0.6	10	458	1.042	47.708
-0.5	13	471	1.354	49.062
-0.4	25	496	2.604	51.667
-0.3	30	526	3.125	54.792
-0.2	20	546	2.083	56.875
-0.1	34	580	3.542	60.417
0	23	603	2.396	62.812
0.1	25	628	2.604	65.417
0.2	28	656	2.917	68.333
0.3	27	683	2.813	71.146
0.4	23	706	2.396	73.542
0.5	24	730	2.500	76.042
0.6	19	749	1.979	78.021
0.7	15	764	1.563	79.583
0.8	21	785	2.188	81.771
0.9	9	794	0.938	82.708
1	11	805	1.146	83.854
1.1	6	811	0.625	84.479
1.2	19	830	1.979	86.458
1.3	8	838	0.833	87.292
1.4	11	849	1.146	88.437
1.5	11	860	1.146	89.583
1.6	9	869	0.938	90.521
1.7	5	874	0.521	91.042
1.8	10	884	1.042	92.083

Table G-6. Sample of Acceleration/Deceleration Data

ACCEL	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
-17.3	1	1	0.104	0.104
-16	1	2	0.104	0.208
-15.7	1	3	0.104	0.312
-15.2	1	4	0.104	0.417
-14.7	2	6	0.208	0.625
-14.5	1	7	0.104	0.729
-14.3	1	8	0.104	0.833
-13.8	2	10	0.208	1.042
-13.5	2	12	0.208	1.250
-13	1	13	0.104	1.354
-12.7	2	15	0.208	1.562
-12.6	1	16	0.104	1.667
-12.4	1	17	0.104	1.771
-12.1	1	18	0.104	1.875
-11.8	1	19	0.104	1.979
-11.5	2	21	0.208	2.187
-11.4	1	22	0.104	2.292
-11.3	1	23	0.104	2.396
-11.1	4	27	0.417	2.812
-11	3	30	0.313	3.125
-10.9	1	31	0.104	3.229
-10.7	1	32	0.104	3.333
-10.6	2	34	0.208	3.542
-10.5	1	35	0.104	3.646
-10.4	1	36	0.104	3.750
-10.2	2	38	0.208	3.958
-10.1	3	41	0.313	4.271
-10	2	43	0.208	4.479
-9.9	2	45	0.208	4.687
-9.7	3	48	0.313	5.000
-9.6	2	50	0.208	5.208
-9.5	2	52	0.208	5.417
-9.4	1	53	0.104	5.521
-9.3	2	55	0.208	5.729
-9.2	2	57	0.208	5.937
-9.1	5	62	0.521	6.458
-9	2	64	0.208	6.667
-8.9	6	70	0.625	7.292
-8.8	5	75	0.521	7.812
-8.7	4	79	0.417	8.229
-8.6	7	86	0.729	8.958
-8.5	10	96	1.042	10.000
-8.3	7	103	0.729	10.729
-8.2	9	112	0.938	11.667
-8.1	15	127	1.563	13.229
-8	7	134	0.729	13.958
-7.9	7	141	0.729	14.687
-7.8	8	149	0.833	15.521
-7.7	10	159	1.042	16.562
-7.6	11	170	1.146	17.708
-7.5	12	182	1.250	18.958
-7.4	9	191	0.938	19.896
-7.3	7	198	0.729	20.625
-7.2	11	209	1.146	21.771
-7.1	7	216	0.729	22.500
-7	17	233	1.771	24.271

Table G-7. Sample of Before Vehicle Lateral Placement Data

PRELP1	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
12.5	1	1	0.104	0.104
14.2	1	2	0.104	0.208
14.3	1	3	0.104	0.312
14.9	1	4	0.104	0.417
15.2	1	5	0.104	0.521
15.7	1	6	0.104	0.625
16.1	1	7	0.104	0.729
16.9	2	9	0.208	0.937
17.3	2	11	0.208	1.146
17.5	1	12	0.104	1.250
17.7	1	13	0.104	1.354
17.9	2	15	0.208	1.562
18	1	16	0.104	1.667
18.2	1	17	0.104	1.771
18.3	1	18	0.104	1.875
18.4	1	19	0.104	1.979
18.5	1	20	0.104	2.083
18.6	2	22	0.208	2.292
18.7	1	23	0.104	2.396
18.8	3	26	0.313	2.708
18.9	1	27	0.104	2.812
19	8	35	0.833	3.646
19.1	3	38	0.313	3.958
19.2	6	44	0.625	4.583
19.3	7	51	0.729	5.312
19.4	3	54	0.313	5.625
19.5	10	64	1.042	6.667
19.6	15	79	1.563	8.229
19.7	10	89	1.042	9.271
19.8	17	106	1.771	11.042
19.9	16	122	1.667	12.708
20	20	142	2.083	14.792
20.1	23	165	2.396	17.187
20.2	20	185	2.083	19.271
20.3	28	213	2.917	22.187
20.4	27	240	2.813	25.000
20.5	26	266	2.708	27.708
20.6	27	293	2.813	30.521
20.7	22	315	2.292	32.812
20.8	33	348	3.438	36.250
20.9	30	378	3.125	39.375
21	29	407	3.021	42.396
21.1	27	434	2.813	45.208
21.2	24	458	2.500	47.708
21.3	31	489	3.229	50.937
21.4	21	510	2.188	53.125
21.5	26	536	2.708	55.833
21.6	31	567	3.229	59.062
21.7	28	595	2.917	61.979
21.8	31	626	3.229	65.208
21.9	23	649	2.396	67.604
22	19	668	1.979	69.583
22.1	18	686	1.875	71.458
22.2	14	700	1.458	72.917
22.3	19	719	1.979	74.896
22.4	14	733	1.458	76.354

Table G-8. Sample of After Vehicle Lateral Placement Data

POSTLP2	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
14.3	1	1	0.104	0.104
14.9	1	2	0.104	0.208
15.5	1	3	0.104	0.312
15.8	1	4	0.104	0.417
16.2	1	5	0.104	0.521
16.5	1	6	0.104	0.625
16.7	3	9	0.313	0.937
16.8	1	10	0.104	1.042
16.9	1	11	0.104	1.146
17	1	12	0.104	1.250
17.4	1	13	0.104	1.354
17.8	1	14	0.104	1.458
18.3	2	16	0.208	1.667
18.5	2	18	0.208	1.875
18.6	1	19	0.104	1.979
18.9	2	21	0.208	2.187
19.1	1	22	0.104	2.292
19.2	6	28	0.625	2.917
19.3	5	33	0.521	3.437
19.4	7	40	0.729	4.167
19.5	1	41	0.104	4.271
19.6	12	53	1.250	5.521
19.7	8	61	0.833	6.354
19.8	9	70	0.938	7.292
19.9	14	84	1.458	8.750
20	9	93	0.938	9.687
20.1	26	119	2.708	12.396
20.2	24	143	2.500	14.896
20.3	29	172	3.021	17.917
20.4	22	194	2.292	20.208
20.5	29	223	3.021	23.229
20.6	31	254	3.229	26.458
20.7	46	300	4.792	31.250
20.8	29	329	3.021	34.271
20.9	32	361	3.333	37.604
21	35	396	3.646	41.250
21.1	34	430	3.542	44.792
21.2	36	466	3.750	48.542
21.3	29	495	3.021	51.562
21.4	29	524	3.021	54.583
21.5	32	556	3.333	57.917
21.6	26	582	2.708	60.625
21.7	33	615	3.438	64.062
21.8	34	649	3.542	67.604
21.9	26	675	2.708	70.312
22	24	699	2.500	72.812
22.1	28	727	2.917	75.729
22.2	24	751	2.500	78.229
22.3	29	780	3.021	81.250
22.4	13	793	1.354	82.604
22.5	14	807	1.458	84.062
22.6	15	822	1.563	85.625
22.7	17	839	1.771	87.396
22.8	19	858	1.979	89.375
22.9	16	874	1.667	91.042
23	12	886	1.250	92.292

Table G-9. Sample of Before/After Vehicle Lateral Placement Reduction Data

LATPLAC	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
-3.4	1	1	0.104	0.104
-3	1	2	0.104	0.208
-2.9	3	5	0.313	0.521
-2.7	1	6	0.104	0.625
-2.6	5	11	0.521	1.146
-2.5	1	12	0.104	1.250
-2.4	2	14	0.208	1.458
-2.3	1	15	0.104	1.562
-2.2	3	18	0.313	1.875
-2.1	4	22	0.417	2.292
-2	2	24	0.208	2.500
-1.9	6	30	0.625	3.125
-1.8	6	36	0.625	3.750
-1.7	8	44	0.833	4.583
-1.6	4	48	0.417	5.000
-1.5	5	53	0.521	5.521
-1.4	17	70	1.771	7.292
-1.3	16	86	1.667	8.958
-1.2	17	103	1.771	10.729
-1.1	30	133	3.125	13.854
-1	22	155	2.292	16.146
-0.9	24	179	2.500	18.646
-0.8	24	203	2.500	21.146
-0.7	16	219	1.667	22.812
-0.6	35	254	3.646	26.458
-0.5	30	284	3.125	29.583
-0.4	43	327	4.479	34.062
-0.3	31	358	3.229	37.292
-0.2	51	409	5.313	42.604
-0.1	43	452	4.479	47.083
0	43	495	4.479	51.562
0.1	44	539	4.583	56.146
0.2	43	582	4.479	60.625
0.3	47	629	4.896	65.521
0.4	32	661	3.333	68.854
0.5	41	702	4.271	73.125
0.6	33	735	3.438	76.562
0.7	34	769	3.542	80.104
0.8	31	800	3.229	83.333
0.9	28	828	2.917	86.250
1	25	853	2.604	88.854
1.1	19	872	1.979	90.833
1.2	14	886	1.458	92.292
1.3	11	897	1.146	93.437
1.4	7	904	0.729	94.167
1.5	9	913	0.938	95.104
1.6	10	923	1.042	96.146
1.7	9	932	0.938	97.083
1.8	11	943	1.146	98.229
1.9	2	945	0.208	98.437
2	4	949	0.417	98.854
2.1	1	950	0.104	98.958
2.2	3	953	0.313	99.271
2.4	1	954	0.104	99.375
2.5	1	955	0.104	99.479
2.6	2	957	0.208	99.687