DSC North America 2003 Proceedings, Dearborn, Michigan, October 8-10, 2003 (ISSN 1546-5071).

Procedures for Running Nighttime Driving Simulations

John A. Molino
Science Applications International Corporation
Federal Highway Administration
Turner-Fairbank Highway Research Center, HRDS-07
6300 Georgetown Pike, Room F-215
McLean, VA 22101
(202) 493-3381
(202) 493-3390
john.a.molino@saic.com

Stephen D. Greene
Science Applications International Corporation
Federal Highway Administration
Turner-Fairbank Highway Research Center, HRDS-07
6300 Georgetown Pike, Room F-215
McLean, VA 22101
(202) 493-3382
(202) 493-3390
stephen.d.greene@saic.com

September 5, 2003

ABSTRACT

The Federal Highway Administration (FHWA) has recently launched a research program on the visibility of various pavement markers and markings during nighttime driving. The research program employs the FHWA Highway Driving Simulator (HDS) to examine the driver's response to different luminance, patterns and environments for both retroreflective raised pavement markers (RRPMs) and pavement marking (PM) stripes. Since RRPMs and PMs are maximally effective at night, the research program has initially focused on nighttime driving simulations. Nighttime driving simulations pose unique challenges which required the development of specially tailored laboratory operating procedures. The purpose of the present paper is to share the procedures developed at the FHWA with others who may want to launch a research program centered on nighttime driving simulations.

So far the FHWA laboratory operating procedures developed to handle nighttime driving simulations have been used in the HDS for two experiments and one pilot study. One experiment employed 36 research participants in about 9,000 trials, and the other experiment employed 18 research participants in about 2,000 trials. The pilot study employed 14 research participants in about 600 trials. Each study lasted from one to three hours for each participant; and younger, middle-aged and older drivers took part in all three studies. The research participants were dark adapted and remained in the dark for the entire duration of the experiment. Detailed operating procedures were developed to conduct these studies in a safe and efficient manner. A safety audit was conducted for the HDS facility, and indicated safety procedures were adopted. The simulator motion base was equipped with hardware and software interlocks to preclude dangerous motions. Motion/Simulator Sickness Procedures, the subject of a different paper delivered at the present Conference, were developed to handle any motion sickness symptoms which might occur. A system of red astronomical and photographic lights was employed to allow research participants to navigate in the completely darkened laboratory without affecting their dark adaptation. Vision tests were administered to all participants in the dark. Information privacy procedures were adopted to ensure the security and confidentiality of all data and information collected during the experiment.

A series of formal communication instruments was developed to help the experimenter to interact with the research participants in an unambiguous and consistent manner. These instruments included: a Participant Pool Intake Form, which incorporated a Motion/Simulator Sickness Screening procedure; a Record of Informed Consent to ensure ethical and confidential treatment of the participants; a Driving Background Survey Form to collect demographic and driving history information; detailed verbatim Instructions for the Experiment; a Post-Experiment Questionnaire to elicit feedback on the study and the simulation; a Debriefing Form to explain the purpose of the experiment after completion; and a Receipt for Cash, which also requested permission to include the participant's name in the FHWA Participant Database for future studies. Training runs and practice trials were employed to familiarize the research participants with the driving simulator and the driving scenarios. A 250-step detailed Experiment Procedures document covered all aspects of implementing the experiment, most of which were conducted in a completely darkened laboratory.

INTRODUCTION

Background

The Federal Highway Administration's (FHWA) Turner Fairbank Highway Research Center (TFHRC) is conducting a multi-staged research program to study human factors issues associated with the use of roadway pavement markings (PMs) and retroreflective raised pavement markers (RRPMs). These roadway delineation devices provide much needed visual guidance to drivers at night. Over the long term, the FHWA research program will address various applications of PMs and RRPMs, the potential for enhancements to these devices, and assessments of their relative role in overall roadway delineation systems. One of the major facilities employed to conduct this research program is the FHWA Highway Driving Simulator (HDS). The current paper describes some of the procedures that have been developed at the TFHRC to conduct visibility experiments on PMs and RRPMs in the FHWA HDS. Since PMs and RRPMs are particularly effective at night, the initial stages of the research have involved simulations of nighttime driving environments.

In the past driving simulators have proven to be useful in studying driver responses to PMs and RRPMs. Allen et al. investigated the effects of contrast and configuration of PMs on driver performance (1). This effort utilized both driving simulation and field observation methods. It did not consider RRPMs, but demonstrated that a driving simulator could provide useful driver performance data. In another simulation study, McKnight et al. investigated the effects of line width and contrast on lane keeping (2). They found that both variables only had an effect at low contrast ratios. Research performed by Freedman et al. investigated the noticeability requirements for delineation on non-illuminated highways (3). This research investigated delineation systems (which included RRPMs) using static laboratory tests, an earlier version of the FHWA HDS, and field observations. The specific effects of RRPMs could not be isolated, but experience was gained in using the driving simulator for studies of both RRPMs and PMs. In a recent study by Bloomfield et al., the effects of spacing, reflectivity, and location of RRPMs were analyzed using a driving simulator (4). The results of that study showed that recognition distances for curves and intersections generally improved with closer spacing and increased luminance of RRPMs. All of these driving simulator experiments used different methods and procedures. Features of these earlier studies were adapted to help formulate the simulator procedures presently evolving with regard to the FHWA HDS.

Development of Simulator Operating Procedures

Three major factors drove the development of the present HDS simulator operating procedures and substantially impacted their content. Two of these factors were 1) the necessity to create and maintain dark adaptation on the part of all of the research participants, and 2) the unique physical layout and motion capabilities of the HDS and the safety implications thereof. The third factor was the necessity to identify and manage Motion/Simulator Sickness, should a research participant exhibit significant symptoms of distress. This latter factor is not covered in the present paper, but is the subject of a different paper delivered at the present Conference (Hoffman, et al., "Driving Simulator Sickness Management at Turner-Fairbank Highway Research Center"). The purpose of the present paper is to share with other users of driving simulators some of the experience gained at the FHWA in developing special simulator operating procedures to address these factors. Such information should be useful to others who want to develop a research program involving nighttime driving simulations.

The HDS consists of a 1998 Saturn SL sedan car cab mounted on a motion base. The motion base resides beneath the vehicle, and is above the ground. Thus the car cab sits about 0.76 meters (2.5 feet) off the ground, and is surrounded by a platform which personnel must mount via three steps in order to enter or exit the vehicle. Although the motion base was not used in the two experiments reported in the present paper, it was anticipated for use in future visibility experiments with PMs and RRPMs. Therefore the operating procedures were developed to take into account the motion capabilities of the simulator. This motion base has since been employed in a pilot study reported in a different paper delivered at the present Conference (Molino, et al., "Motion Cues for a 3-DOF Driving Simulator"). Some of the safety features concerning the motion base are derived from this latter pilot study, and are reported to demonstrate recent progress in HDS procedure development.

The major portion of the present simulator operating procedures were developed to support two experiments. Both experiments were conducted in 2002, one in the Spring and one in the Fall. The first experiment used both PMs and RRPMs. This first experiment explored the luminance tradeoff between center line PMs and center line RRPMs that could be made and still achieve adequate safety in identifying curves. The second experiment used only PMs. This second experiment explored the luminance tradeoff between center line PMs and edge line PMs that might be made while maintaining adequate safety. Both experiments used curve recognition distance as the primary dependent variable. Both experiments simulated driving down a rural two-lane roadway in two different night environments. The first environment was a dark but clear night, representing normal nighttime driving conditions, with the roadway edge, road texture, a grassy plain and a horizon visible in the simulated scene. The second environment was a dark and rainy night, represented by a completely black background, with only the PMs and/or RRPMs visible in the simulated scene.

TWO EXPERIMENTS

The two experiments which employed the present procedures are described below. The only part of the procedures that was not fully implemented in those two studies concerned the simulator motion base. The experiments are described before the procedures so that they may provide a context for understanding the procedures.

Research Participants

Research participants were recruited from the area surrounding McLean, Virginia. Each research participant possessed a valid U.S. driver's license and passed vision test. The criterion for passing the vision test was at least 20-40 visual acuity in each eye (corrected if necessary).

In the first experiment there were 36 research participants. The 36 research participants were divided into three age groups of 12 participants each: younger drivers (age 18 to 30 years), middle-age drivers (age 31 to 64 years) and older drivers (age 65 years and above). These age groups contained equal proportions of male and female participants (6 of each gender). The experiment took about 3 hours to complete. Each participant was paid $100 upon successful completion of the study.

In the second experiment there were 18 research participants. The 18 research participants were divided into three age groups of 6 participants each: younger drivers (age 18 to 30 years), middle-age drivers (age 31 to 64 years) and older drivers (age 65 years and above). These age groups contained equal proportions of male and female participants (3 of each gender). The experiment took about 2.5 hours to complete. Each participant was paid $80 upon successful completion of the study.

Special procedures were developed to ensure the privacy, confidentiality and anonymity of the research participants.

Experimental Variables

The independent variables in the set of two experiments were as follows:

1. Presence/absence of yellow Center Line PMs on the simulated roadway
2. Presence/absence of a single row of yellow RRPMs down the center of the simulated roadway
3. Presence/absence of white Edge Line PMs on the simulated roadway
4. Luminance of yellow Center Line PMs on the simulated roadway (three values: High, Medium and Low)
5. Luminance of yellow RRPMs on the simulated roadway (three values: High, Medium and Low)
6. Luminance of white Edge Line PMs on the simulated roadway (three values: High, Medium and Low)
7. Length of the tangent segment of the simulated roadway (two sets of 5 values each, each set correlated with instructed speed)
8. Degree of curvature of the simulated curve: 6 degrees per 30.5 meters (100 feet) or 10 degrees per 30.5 meters (100 feet), correlated with instructed speed
9. Direction of the simulated curve: right or left, randomly assigned
10. Instructed driving speed: 56.4 or 88.6 km per hour (35 or 55 MPH)

11. Darkness of the driving environment: a night driving scene or a totally black background.

The dependent variables in the set of two experiments were as follows:

1. Curve detection/recognition distance: distance in meters from the beginning of the curve in the simulated roadway to the projected center of gravity of the vehicle on the simulated roadway at the moment the research participant pressed either the right or the left response button
2. Direction of the curve detection/recognition response: either right or left, corresponding to whether the participant pressed the right or left response button on a given trial
3. Vehicle speed at the instant of a curve detection/recognition response: the simulator vehicle speed in km per hour at the moment the research participant pressed either the right or the left response button
4. Vehicle lateral lane position at the instant of a curve detection/recognition response: the coordinate position of the projection of the center of gravity of the simulator vehicle on the simulated roadway at the moment the research participant pressed either the right or the left response button, expressed in meters from the right roadway edge
5. Individual participant responses to 10 questions on a Background Survey administered before the beginning of practice trials
6. Individual participant responses to questions on a Post-Experiment Questionnaire administered after the completion of the experimental trials.

Stimulus Generation

The experiment was conducted in the fully interactive HDS located at the TFHRC. As mentioned above, the simulator consisted of a 1998 Saturn SL sedan car cab mounted on a motion base. A loudspeaker system provided engine and roadway noise. A curved projection screen in front of the car cab provided an 88-degree field of view of the simulated roadway environment, with a vertical field of view that covered the entire windshield. Scene elements were generated by both the Multigen Creator real time modeling package and through dynamic scene graphics programming. The computer graphics were rendered in real time by an SGI ONYX2 computer with Infinite Reality Engine graphics. The algorithm used an OpenGL Performer 3D rendering API to generate real-time 3D graphics images projected by an Electrohome Marquee Model 9500LC video projector. The color temperature of the projector was 6500K at a resolution of 1920x960x24bit color RGB. The scene was refreshed at a nominal 60-Hertz frame rate.

Nighttime lighting was simulated by using the standard OpenGL shading model, and specifically setting the emissive RGB values for the lane markings based on headlight distance as shown in Table 1. The center lines were yellow and the edge lines were white. The luminance of the center lines ranged from 0.61 to 0.047 cd/m^2 and the luminance of the right edge lines ranged from 1.2 to 0.51 cd/m^2. The luminance of the RRPMs ranged from 4.1 to 0.19 cd/m^2. The average luminance of the roadway was about 0.0078 cd/m^2. Thus the maximum contrast ratio for the roadway delineation was about 520 to 1.

TABLE 1 RGBE Values for Pavement Markings

Luminance	Left Edge Line	Center Line	Right Edge Line
High	72, 72, 72, 1.0	55, 55, 0, 1.0	27, 27, 27, 1.0
Medium	27, 27, 27, 0.9	28, 28, 0, 0.55	27, 27, 27, 0.4
Low	17, 17, 17, 0.5	28, 28, 0, 0.35	17, 17, 17, 0.0626

The motion base was turned off during both experiments. Since the research participants were instructed to drive straight roads at a constant speed for the entire driving scenario, there was no compelling need to implement motion cues.

Trial-based Methodology

A certain combination of RRPMs, center lines and/or edge lines was simulated on a rural two-lane roadway segment. This roadway segment began as a straight (tangent) roadway segment that, in most cases, turned either to the right or to the left after a short distance. The research participant drove the simulator vehicle along this simulated straight roadway until she/he detected a curve and could recognize whether the curve turned to the right or to the left. At that point the research participant pressed one of two response buttons located on the steering wheel of the car. One button was located on the right side of the steering wheel and the other button was located on the left side, at approximately the 10 and 2 o'clock positions. The participant pressed the button that corresponded to the perceived direction of the curve ahead.

At the instant the research participant pressed one button or the other, the scenario shifted to the next trial. Then the research participant drove down a new straight roadway segment, in most cases with a curve located some random distance down the roadway. If the research participant failed to recognize the curve before the car was over the beginning of the curved road segment, the current roadway segment automatically switched to the next segment as described above. There were a few roadway segments that did not lead to any curve. These served as blank trials. In these cases, the scenario changed to the next roadway segment without any response from the research participant once the simulator vehicle reached the end of the tangent (straight) roadway segment. These blank trials were inserted to provide a measure of the false alarm rate maintained by the participants and thereby monitor their response criterion.

Experimental Design

A single block of experimental conditions consisted of 16 different combinations of four luminance levels for the center line PMs combined with either four luminance levels for the RRPMs in the first experiment, or with four luminance levels for the edge lines in the second experiment. The 16 combinations were derived by crossing the None, Low, Medium and High luminance levels of each type of delineation treatment used in the particular experiment. Since the curve at the end of the tangent segment could turn either right or left, that made 32 different roadway configurations. Each block of 32 roadway conditions was presented in one of four combinations of environmental lighting and instructed driving speed. The environmental lighting conditions consisted of the night driving scene and the totally black background described above. The instructed driving speeds were either 56.4 or 88.6 km per hour (35 or 55 MPH). In the None-None condition in the black background, where there would be no cues to drive by, a faint road texture was added. This road texture was not present in any other black background condition.

Altogether, there were 32 roadway delineation treatments and four driving parameters in each experiment -- a total of 128 conditions, or 128 trials. In addition, there was one blank trial (with no curve) out of every 16 trials, resulting in a total of 136 trials in each experiment. Each participant in the first experiment completed two repetitions of each combination, for a total of 272 trials. Each participant in the second experiment completed only one combination, for a total of 136 trials. These trials were organized into blocks having a given combination of speed and nighttime driving condition. Practice trials were given at the beginning of the experiment to familiarize the research participants with the driving simulator and the scenarios. The first experiment collected data from about 9,000 trials over 5 weeks, and the second experiment collected data from about 2,000 trials over 3 weeks.

SAFETY PROCEDURES

Safety Audit

Before the final simulator procedures were developed for the first experiment, a formal safety audit was conducted at the HDS. The safety audit was based on questions abstracted from the Occupational Safety and Health Administration (OSHA) Safety Inspections Checklists (5). The safety audit covered such items as fire extinguishers, flammable materials, hand tools, power tools, lockout and tag-out procedures, confined spaces, electrical hazards, fuses, walking and working surfaces, slipping and tripping, hazard communications, etc. Safety trials were conducted in both the lit and the darkened simulator chamber. Several safety improvements were made as a result of this safety audit. Two examples include the upgrading of exit signs in the simulator chamber so that they could be seen in the dark, and the addition of aircraft-type aisle lighting to illuminate the stairway to the simulator platform. The stairs and aisles were also marked with reflective tape. The experimenter always accompanied the participant to and from the car

DSC North America 2003 Proceedings, Dearborn, Michigan, October 8-10, 2003 (ISSN 1546-5071).

cab to minimize the risk of the participant catching a hand or a foot in the car door. The experimenter carefully observed the participant in all entry and exit maneuvers to minimize such risks.

Illumination

The nighttime driving conditions of the initial experiments required that the research participants be dark adapted for at least 20 minutes before driving in the simulator. Thus it was decided that all paperwork associated with Informed Consent, the vision screening test, all preliminary survey forms, all verbatim instructions, etc. be given to the research participants while they were in the dark, so as to take advantage of this time as part of their dark adaptation. A combination of red photographic and astronomical lights was employed to allow participants to read forms and instructions and to navigation on the platform while the simulator chamber was otherwise in total darkness. A small desk lamp with a red photographic darkroom bulb was placed on a desk so that participants could read and fill out forms. The participant and the experimenter each wore a small portable astronomical observation flashlight around her/his neck at all times. These flashlights were Red Beam II LED Variable-Brightness Astro models manufactured by Orion. They were worn to ensure safe movement on the simulator platform as well as entering and exiting the car cab. Each flashlight had a small LED bulb which emitted a very narrow band of red light. Such a red line spectrum of light allows an astronomer to write down observations of what was being seen through a telescope at night, without light adapting the astronomer's eyes. These small flashlights were often employed by the research participants to supplement the red photographic light in reading documents. The photographic lamp and astronomical flashlights were turned off during driving sessions in the simulator. However, even under these conditions the research participant was not in total darkness. There was always some minimal illumination from the projection screen, and the car cab instrument lights provided some additional low-level illumination. At the other extreme, should an equipment failure flood the entire chamber with light, the simulator projector/screen and the laboratory lighting were not capable of producing intense visual stimuli that could damage a person's eyesight.

Motion

The HDS utilizes a 3 Degree of Freedom (DOF) motion base. The motion base mechanism is manufactured by Servos and Simulation, Inc., of Maitland, Florida. The 3 DOFs produced by the motion base are vehicle pitch, roll, and heave (z-axis). The motion base has the capability to generate low frequency vibrations to simulate roadway surface textures as well. Table 2 shows the physical angular and linear limits of motion:

TABLE 2 Summary of HDS Motion Limits

Degree of Freedom (DOF)	**Mechanical Limits**		**Software Imposed Limits (Filters)**	
Pitch	+14.61^{0} to -13.84^{0}	Front Bumper +532 mm to -504 mm (+20.93 in to -19.86 in)	±12%	Front Bumper ±438 mm (±17.26 in)
		Rear +576 mm to -533 mm (+22.69 in to -20.98 in)		Rear ±475 mm (±18.71 in)
Roll	±18.88^{0}	Side ±271 mm (± 10.68in)	±15%	Side ±217 mm (±8.54 in)
Heave (z-body axis)	±203 mm (±8 in)		±203 mm (±8 in)	

Beyond the above mechanical and software limits, additional procedural and software-based safety protocols were imposed. First, the elevated area surrounding the motion platform and the car was equipped with railings and chains that restrict access to the vicinity while the motion base is operating. Second, the simulator software restricted any motion unless the motion base was powered, and an operator enable button was activated at the control console. The simulation procedures required that the operator ensure that all staff and research participants were secured in their proper positions before the motion base was enabled. Third, the procedures required that a trained safety observer from the HDS staff be present during all operation of the motion base. This requirement ensured that a person in the loop can freeze and shutdown motion in an emergency situation. Fourth, no motion was activated until the vehicle had been placed in a non-parked shift position and the driver's seat belt had been fastened. Motion was also not possible until the car doors were closed, and immediately ended (was frozen in the current position) if the car doors are opened. In addition, whenever the motion base was active, the action of the motion base was displayed on a CCTV monitor located at the control console in the control room. At all times while the participant was enclosed in the car cab, the experimenter observed the vehicle motion on this CCTV monitor to verify that the motion base was operating correctly. All of these interlocks and procedures were designed to ensure the safety of operators, experimenters and research participants when using the motion base capability of the HDS.

Acoustics

The simulator was equipped with a loudspeaker system which produced roadway sounds. The simulator was also equipped with an intercom system for safety. Whenever the research participant was in the car cab alone, the experimenter observed the participant by means of an infrared video camera, and was in constant voice communication by means of the intercom system. The intercom system inside the simulator car cab and the roadway noise loudspeaker external to the car cab were limited to producing no more than 90dB(A) of sound level, even when operated simultaneously, so as not to damage a person's hearing. The infrared video camera and the audio microphone in the car cab were not attached to any recording devices. To insure privacy, no video or audio taping of participant behaviors was made.

EXPERIMENT PROCEDURES

Formal Participant Communications

A series of formal communication instruments was developed to help the experimenter to interact with the research participants in an unambiguous and consistent manner. The particular instruments used as examples came from the second experiment. These instruments are listed in the order in which they were administered to each research participant. They are:

1. Participant Pool Intake Form
2. Motion/Simulator Sickness Screening Form
3. Record of Informed Consent
4. Background (Demographic) Survey
5. Instructions for Experiment
6. Post-Experiment Questionnaire
7. Debriefing
8. Receipt for Cash.

Typical Sequence of Events

Before the research participant even reached the laboratory, communication was established by telephone. The Participant Pool Intake Form and the Motion/Simulator Sickness Screening Form were administered to qualify the perspective research participant. If the participant qualified for the particular experiment, she/he was scheduled to come to the TFHRC for testing.

Upon arrival at the TFHRC, the participant was greeted at the security desk, was asked to show her/his driver's license, and was escorted to the laboratory. The experimenter explained that data collection could last one to three hours in the dark, depending on the requirements of the particular experiment. In order to provide for the participant's comfort, the experimenter encouraged the participant to use the drinking fountain and noted that bottled water would be offered during breaks in the experiment. The experimenter also encouraged the participant to use the restroom prior to beginning, emphasizing that any necessity to leave the simulator room, although permissible, would require at least a 20-minute delay to recover dark adaptation.

Once inside the simulator room and its control room, the experimenter showed the participant the exit signs and doors for emergency egress. The experimenter introduced the research participant to the HDS staff. Then the participant was led to a desk on the simulator platform and asked to sit down. The experimenter briefly explained that the participant's vision needed to be dark-adapted, and then turned off the simulator chamber lights. The participant was considered to be adapted after about 20 minutes in the dark, during which time she/he completed formal written communications. These communications included a Record of Informed Consent to ensure adherence to ethical standards, a Background Survey (see Exhibit 1) to collect relevant demographic information, and a Simulator Sickness Questionnaire (SSQ) to screen for any current symptoms of motion/simulator sickness.

During the dark adaptation period, the experimenter also readied the vision tester, a Titmus II Vision Screener manufactured by Titmus Optical, Inc. Visual acuity and color deficiency tests were administered to ensure minimum visual capabilities, as defined by Virginia state driver licensing criteria. A participant who wore glasses or contact lenses while driving, also wore them for vision testing and for all experimental sessions. Over 90 percent of participants achieved a visual acuity of 20/40 or better (corrected, if necessary). In testing 56 participants, only two had to be eliminated because they did not meet the vision requirements for the two experiments.

After completing the vision test, each participant read the Instructions for Experiment (Exhibit 2). The experimenter answered any questions, and asked the participant to open the car cab door and sit in the driver's seat. The participant adjusted the seat position and steering column if needed, and closed the car door. The experimenter requested the safety belt be fastened; and briefly explained the controls of the simulator automobile. These included the response buttons on the steering wheel, the infrared camera, the intercom, and the sickness bag. If the participant had no further questions, the experimenter left the simulator chamber and entered the control room to begin the first block of trials. Except in pilot studies, this first block of trials usually consisted of practice trials.

After a participant completed each block of trials, the participant was asked how she/he felt to monitor for symptoms of motion/simulator sickness. A break was usually announced to allow time for the participant to relax, and for the experimenter to load the next driving condition. Depending on the experiment, this break could last from one to 10 minutes. In a typical experiment between two and 8 blocks of trials might be run in a single dark-adapted session, punctuated by breaks of differing durations.

At the conclusion of the data collection trials, the experimenter asked the participant to close her/his eyes, before the simulator chamber lights were turned on. The participant exited the car cab when ready, after her/his vision adjusted to the light. The participant sat at the table to complete a Post-Experiment Questionnaire (Exhibit 3), eliciting further information about participant reactions, and then read a Debriefing statement (Exhibit 4), describing the purpose of the experiment. The experimenter answered any questions from the participant, and compensated the participant for her/his time. A Receipt for Cash was executed by both the experimenter and the participant. The participant was thanked for her/his participation, escorted back to the entrance, and encouraged to participate in future experiments.

Detailed Procedures Document

A 250-step detailed Experiment Procedures document covered all of the above aspects of implementing the experiment, from signing the participant in at the security desk, to familiarizing the participant with the safety features of the HDS laboratory, to the administering preliminary tests and forms, to explaining the operation of the car displays and controls, to conducting practice sessions, to managing breaks, to conducting experimental sessions, to administering post-experiment surveys and forms, and finally to escorting the participant back to the security desk. Most of these activities were conducted in a completely darkened laboratory. This detailed Procedures document ensured the smooth and consistent operation of the experiment for all of the 54 participants who were tested in the two studies.

SUMMARY OF RESULTS

The focus of the two experiments was to determine the relative luminance of RRPMs and edge lines when combined with center line pavement markings (PMs) needed to produce adequate guidance on rural two-lane roadways at night. The primary driver performance measure was curve recognition distance. For the various RRPM and PM luminance conditions, mean curve recognition distances ranged from 19.0 meters (62.3 feet) to 68.4 meters (224 feet), with a grand mean of about 43.2 meters (142 feet). Regression analyses produced predictive equations to estimate the mean curve recognition distance from the luminance of RRPMs acting alone, of edge lines acting alone and of center lines acting alone. Trading ratios were computed for center line luminance with and without RRPMs present on the road, as well as for center line luminance with and without edge lines present on the road. Conservative empirical estimates of 0.52 (for RRPMs) and of 0.41 (for edge lines) were obtained for such trading ratios based on the data from the two experiments. The RRPM value of 0.52 may be compared with independent estimates from earlier studies of from 0.52 to 0.55. Thus the current experiments provide preliminary indication that it might be possible to allow the luminance of center lines on rural two-lane roads to degrade by about 45 percent when appropriate RRPMs are present, and by about 60 percent when appropriate edge lines are present.

ACKNOWLEDGEMENTS

The work reported herein was conducted for the Federal Highway Administration (FHWA) under two separate contracts. One contract was with Science Applications International Corporation (SAIC), and the other was with AAI / Engineering Support, Inc. Many individuals from these three entities, as well as from other FHWA contracting organizations, helped to make this research possible. Teamwork was at the core of the effort. The authors wish to express special appreciation for guidance and direction to Thomas M. Granda and M. Joseph Moyer of the FHWA Human Centered Systems Team, and to Stephen A. Fleger of SAIC and Barry Wallick of AAI/ESI. Kenneth S. Opiela of the FHWA Roadway Team assisted in sponsoring the work. The HDS was set up and programmed by Jason R. Williams, Duoduo Liao and John M. Wink, who offered many valuable suggestions for the present operating procedures. Ronald B. Hoffman engineered and managed the procedures to minimize simulator sickness. Vladislav Popov reduced and analyzed the data. The authors are grateful to all who helped to make this endeavor a success.

REFERENCES

1. Allen, R.W., O'Hanlon, J.F., and McRuer, D.T. Driver's Visibility Requirements for Roadway Delineation. Volume I: Effects of Contrast and Configuration on Driver Performance and Behavior. Report No. FHWA-RD-77-165. FHWA, U.S. Department of Transportation, Washington, DC, November 1977.

2. McKnight, A.S., McKnight, A.J., and Tippetts, A.S. The Effect of Lane Line Width and Contrast Upon Lanekeeping. *Accident Analysis and Prevention*, Vol. 30, No. 5, 1998, pp. 617-624.

3. Freedman, M., and Staplin, L.K. Noticeability Requirements for Delineation on Nonilluminated Highways. Report No. FHWA-RD-88-028. FHWA, U.S. Department of Transportation, Washington, DC, July 1988.

4. Bloomfield, J.R., Brown, T.L., Durlak, C.F., and Bartelme, M.J. The Effect of Varying the Spacing, Reflectivity, and Location of Retroreflective Raised Pavement Markers (RRPMs) on Driving Performance. Prepared for FHWA, Washington, DC, June 2000 (publication pending).

5. Occupational Safety and Health Administration (OSHA). Safety Inspections Checklists. http://www.osha.gov/SLTC/smallbusiness/chklist.html. Accessed Apr. 15, 2002.

EXHIBITS

The following section presents some examples of the formal communications conducted between the experimenter and each research participant in the second experiment. Not all of the 8 documents listed above are shown in these Exhibits. Some of the forms were standard in experimentation with human research participants, some were concerned with Motion/Simulation Sickness, and others were highly specific to idiosyncrasies of the given experiment. The documents that are depicted reveal some important aspects of conducting simulator experimentation in the dark, or stand as examples of the carefully controlled nature of experimenter/participant communications in these studies.

EXHIBIT 1

Participant Number: ________

BACKGROUND SURVEY

1. How would you characterize your Overall Health (check one)?

- ? Excellent ______
- ? Very Good ______
- ? Good ______
- ? Fair ______
- ? Poor ______

2. Age when you received your driver's license: ______ years; Where? ____________

3. Approximately how many miles do you drive each year? ________ miles

4. What percentage of your driving is done at night? ________ percent

5. How would you characterize your eyesight (check one)?

- ? Excellent ______
- ? Very Good ______
- ? Good ______
- ? Fair ______
- ? Poor ______

6. Do you have any night vision problems? ________No ________Yes

7. Do you have any other vision problems? ________No ________Yes

8. If you answered yes to either Number 6 or 7 above, what are those problems?

9. Gender (check one): ________ Female _________ Male

10. Age: _______ years

EXHIBIT 2

INSTRUCTIONS FOR EXPERIMENT

In this experiment you will drive in a simulator. The simulator car has an automatic transmission and drives like a traditional automobile. One modification to the car is the attachment of two small white buttons to the steering wheel. These are your response buttons to indicate when you recognize a curve in the road. The buttons are extremely sensitive, so please touch them only when you recognize a curve ahead in the road. Press them now and as soon as you get in the car cab each time, to see how they feel. In order to keep your fingers near the buttons, you should drive with your hands at the 10-o'clock and 2-o'clock positions on the steering wheel. Another modification to the car is the addition of a microphone and loudspeaker inside the cab. These devices permit two-way voice communications between you and the experimenter in the next room.

In this experiment you will drive along a straight and level roadway segment which almost always leads to a curve. As soon as you are sure that you recognize a curve in the road, you will press the appropriate response button. If the curve goes to the right, you will press the right-hand button on the steering wheel. If the curve goes to the left, you will press the left-hand button on the steering wheel. Only press the button when you are sure that you see the curve and can recognize its direction.

As soon as you press either response button, you will automatically be transferred to the next roadway segment. If you fail to recognize the curve before you get to it or if there is no curve, you will automatically be transferred to the next roadway segment. You will hear a short higher-pitch "beep" every time you make a correct response. A correct response is whenever you correctly identify the direction of the upcoming curve or make no response when no curve is present. You will hear short lower-pitch "beep" every time you make an incorrect response or fail to respond. These lower-pitch "beeps" will occur every time you confuse the direction of the curve, miss the curve or respond when there was no curve present.

All of the roadway segments are two-lane rural roads. There will be various combinations of roadway marking lines on most of the roadway segments. The roadway segments are arranged in blocks of 34 segments to a block. It will take about 10 minutes to complete a block. During an entire block of roadway segments you should maintain a given speed. The experimenter will tell you before each block what speed you should maintain.

Some of the roadway segments will be well marked. In these cases it will be rather easy to drive the segment and recognize the upcoming curve. Other roadway segments will have little or no roadway markings. In some of these cases it may be more difficult to drive the segment and recognize the upcoming curve. Remember to only press the button when you are sure that you see the curve. Regardless of the difficulty of the task, try to maintain the given speed while staying in your lane.

The car will be idling in Park when each block of trials begins. There will never be any need for you to use the ignition key. When the experimenter says "Ready", put the car in Drive, increase your speed and maintain the instructed speed. Remember that your primary driving tasks are to recognize curves, maintain the instructed speed and stay in your lane. As soon as you are sure that you recognize a curve in the road, press the appropriate button. Press the right button for curves to the right, and press the left button for curves to the left.

This is not a test of your personal driving skill and no personal performance information will be maintained or shared with authorities. Relax and do your best. Remember to always drive with your seat belt fastened, even in our simulator. Remember also that you can withdraw consent and discontinue participation in this experiment at any time. If you have any questions, please ask the experimenter now.

Now we are ready to begin a practice block of 34 trials. This will take about 10 minutes. The experimenter will be in the car with you for this first practice block of trials. The experimenter will instruct you on what speed to maintain.

EXHIBIT 3

POST-EXPERIMENT QUESTIONNAIRE (TRUNCATED)

Note: In all questions with a rating scale, please circle only one number.

1. **Overall, how would you rate the task of detecting the curves?**

Easy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Difficult

Under what conditions was it difficult? ____________________________________
____
____

Under what conditions was it easy? ____
____
____

2. **Overall, how would you rate the task of maintaining your speed?**

Easy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Difficult

Under what conditions was it difficult? ____________________________________
____
____

Under what conditions was it easy? ____
____
____

3. **Overall, how would you rate the task of staying in your lane?**

Easy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Difficult

Under what conditions was it difficult? ____________________________________
____
____

Under what conditions was it easy? ____
____
____

AND 7 OTHER QUESTIONS

EXHIBIT 4

DEBRIEFING

Thank you for participating in this experiment. The data that you provided today will help the Federal Highway Administration (FHWA) in making recommendations to highway engineers concerning improved roadway delineation. Such roadway delineation is applied to give guidance to the driver and thereby to make roadways more safe. However, when designing a new road, or enhancing an old road, highway engineers need to know how much of each kind of roadway delineation treatment to use. In the case of the experiment which you just completed, we are concerned with two important types of roadway delineation. They are the yellow Center Lines and white Edge Lines often found along roadways.

We are determining by means of a simulator experiment the trade-off between these two types of roadway delineation. More specifically, how much brightness of the Center Lines may be traded against, or compensate for, the brightness of the Edge Lines, and still achieve the same degree of safety in detecting curves in the road. This is why you saw Center Lines and Edge Lines of different brightness levels and different brightness combinations in the simulated driving scene. Among other things, we were measuring how far away you could see a curve under these different conditions of roadway delineation.

This information will be of value to highway engineers for designing optimal roadway delineation. Such technical information can potentially benefit the entire driving public by making night driving more safe.

We are grateful for your helping us in this experiment. We hope that it was interesting and fun. We hope that you will want to come back and participate in other experiments and studies for FHWA in the future. We ask that you not discuss the details of this experiment with anyone for a period of 90 days. This will help to insure that future research participants in this experiment do not acquire any special information or biases. Thank you.