COMPARISON OF A COMPUTER GENERATED DISPLAY AND A SIMULATED MOTION PICTURE DISPLAY IN DRIVING SIMULATION

by

Peter P. Fung

Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Industrial Engineering and Operations Research

APPROVED:

Dr. W. W. Wierwille, Chairman

Dr. H. L. Snyder

Dr. J. A. Sgro

November, 1974

Blacksburg, Virginia

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to , major advisor, for his guidance and encouragement throughout this research, to for his valuable statistical and editoral comments, and to for his many useful suggestions.

Special thanks goes to , , and for their assistance in the experimental data gathering, and to for his advice in computer programming. Thanks are due to the General Motors Corporation for support of the project on Human Performance in Simulated Driving Tasks.

The author is also grateful to for her time and patience in typing this thesis.

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INTRODUCTION

In studying driver performance under various behavioral and environmental conditions, many investigators have recognized the automotive driving simulator as a useful tool. Advantages of using a simulator over the full-scale on-the-road methods generally include better control and repetition of experimental conditions, easier set up and use of sensing and recording equipment, and improved safety (Wierwille, 1973). The advantages of a driving simulator cannot however be fully realized without an accurate, realistic simulator.

In general, past simulators have been part-task in nature and have had only limited areas of application. Design and construction costs for a full-task simulator appear prohibitive for any given single organization. Because driving simulators are part-task, questions regarding the realm of applicability naturally arise. What kind of simulator should be used? What should be the nature of the display system? How much fidelity is required? As simulators become more widely used, questions such as these will require answering.

Simulators quite often are classified according to the display generating technique and according to amount and number of degrees of physical motion. From a display standpoint, the most widely used classifications are as follows:

(1) Motion Picture Display Simulator (MPDS). Film taken on a roadway is projected in some way for viewing by the driver/subject (Beinke and Williams, 1968; Hulbert and Mathewson,

1958).

(2) Closed Circuit TV-Terrain Model Display Simulator. A large terrain model with a miniature roadway system and model buildings is used in this kind of simulator. A movable TV camera and a television projector or monitor are used to provide a visual scene (Hutchinson, 1958; Weir and Wojcik, 1971).

(3) Computer Generated Display Simulator (CGDS). A computer is used to generate signals that are applied as inputs to a computer display that is viewed by the driver/subject. The image of the roadway and any other environmental features are programmed on the computer (Wierwille, 1973).

(4) Point-Light-Source or Shadow Projection Display Simulator. This type of simulator uses a fixed point light source and a transparent model. Light passing through the transparency is projected onto a screen and thus is viewed by the driver (Heimstra and McDonald, 1973).

Each of these display approaches possesses advantages and disadvantages for conducting research studies or performing training. For example, the MPDS approach has the advantage of cue richness and wide angle presentation. The CGDS approach, on the other hand, can be made completely closed-loop and therefore possesses the potential for being dynamically accurate.

This research study was undertaken with the purpose of comparing two of the above four approaches, namely the MPDS and the CGDS. In addition to its cue richness, the MPDS has the advantage of economy and content realism. Thus there is a strong impetus to use this approach to the maximum extent possible. The CGDS, being dynamically accurate, is best suited for studies of handling qualities; however, the CGDS is usually very expensive both in hardware and in software costs. Consequently, a researcher or educator might wish to avoid the use of a CGDS if an MPDS will not compromise the experimental results.

A literature search indicates that no previous work has been done to compare computer generated and motion picture displays for driving simulators. Furthermore, little has been done to optimize or make best use of motion picture displays in driving simulators. The precise changes in driver response that are caused by the dynamic limitations of motion picture simulators are largely unknown.

STATE OF ART IN COMPUTER GENERATED AND MOTION PICTURE DISPLAYS IN DRIVING SIMULATION

The technique of using computers to generate simulated roadways for driving simulation is relatively recent. Learner (1960) first described a minimal driving simulator in which a pulse-width modulation tape recording system was used to record the roadway geometry. The signal was recovered through a reproduction system in the tape transport unit to provide an input for a road curvature display. Display signals from the tape were represented by five horizontal bars in an inverted V configuration displayed on a cathode ray tube. The relative position of these bars provided information about the width and curvature of the road. Two vertical bars on the CRT represented the width and lateral deviation of the vehicle. Feedback of the driver's steering control was limited to lateral position of the vehicle. Yaw, roll, pitch, and vertical position were not provided. Variation of vehicle velocity was achieved by changing the tape speed, which was controlled by the driver's accelerator input. Although this computer-driven simulator did not furnish all the necessary visual, auditory, and motion cues in a driving task, it did provide certain basic cues which were sufficient in some driving studies.

Sheridan, Paynter, and Coons (1964) proposed an alternative method of generating an artifical roadway. Instead of using prerecorded signals, a real-time random signal generator and a sinusoidal function generator were used to generate a sliding waveform which appeared like a roadway in perspective similar to that seen by the driver through his windshield. This technique achieved a more realistic visual simulation of the roadway and was adopted by many later developers of driving simulators.

With the Swedish Traffic Safety Council, the SAAB company of Sweden developed a driving simulator in which roadway signals were prerecorded on paper tapes; the display was projected from a cathode-ray tube onto a translucent screen in front of the driver. A collimating lens was placed between the driver and the screen to give an increased depth effect. The simulated roadway, which was composed of 16 straight lines, was generated from the paper tape by an analog computer. The sensation of real movement was achieved by moving the entire framework of the simulator from side to side up to 18 inches. This simulator was designed to study driver reactions to various "obstacles", and to serve as an educational tool (Electronics, 1967).

The Cornell Aeronautical Laboratory (CAL), Inc. Driving Simulator (Wierwille, Gagne, and Knight, 1967) utilized an improved version of the technique proposed by Sheridan et al (1964). The simulated roadway, which was composed of a solid center line, two dotted side lines, and roadside posts, was projected onto a lenticular screen by a Schmidt projector. Lateral translation and rotation of the vehicle were simulated by modifying the roadway image electronically. A later version of the CAL driving simulator (Sugarman, Cozad, and Zavala, 1973) was built on a moving base with which roll and yaw motion were provided. A Schmidt projector was placed in front of the driver's cabin to project the roadway image onto a rear projection screen. A collimating lens was used to produce proper perspective. The Virginia Polytechnic Institute and State University (VPI & SU) driving simulator, also developed by Wierwille, bear resemblance to the later CAL simulator, on which he also performed the preliminary design.

The Volkswagen driving simulator (Lincke, Richter, and Schmidt, 1973) employs a display technique similar to that of the SAAB simulator. Paper tapes are used to record roadway curvature, and an analog computer calculates the dynamic state of the vehicle. A moving base that permits rotation of the driver's cabin around three axes is scheduled to be built.

Currently, a feasibility study of the applicability of the computer graphic technique to a visual-environment simulator is being undertaken by the Highway Safety Research Center, Chapel Hill, North Carolina. Basically, a pre-defined data set which describes a planar view of the terrain is stored in the computer. In operation, the computer selects a proper section of the data set corresponding to the terrain and accepts the driver's steering, acceleration, and braking signals to compute and display graphically the dynamic environment on a CRT display system. This operation involves as much as 7000 instructions to be executed in about 1/30th of a second. Advantages of such display techniques over the other prerecorded roadway techniques are the realism of the display and the feeedom of the controlling the vehicle. The driver in this kind of simulator can drive the vehicle in any direction he wishes, whereas in other simulators the driver must stay on the road or near the road. However, this simulator has not been demonstrated in a real-time application.

The motion picture display technique was frequently used in the driving simulators developed earlier. Typically, a projection screen is placed in front of the vehicle mock-up and a film projector is mounted above the driver's cabin to project roadway and environmental displays. Some variations of this technique are the use of extreme wide angle lenses (such as cinemascope), front and rear projection, and cinerama or bellerama (circlerama). In the control system, the driver's accelerator inputs are usually linked to the projection speed, whereas steering inputs are linked to the horizontal projection angle. Sophisticated simulators may use multichannel projectors to provide lateral movement simulation, but the impression of lateral jumps of the vehicle when the projector switches from one film strip to another is the essential problem to be solved. Brief descriptions of some motion display driving simulators are given below.

Hulbert and Mathewson (1958) of the Institute of Transportation and Traffic Engineering of UCLA developed a driving simulator employing the motion picture display technique. An automobile with its rear wheel on steel rollers was used as the vehicle mock-up. The forward picture was projected on a curved screen 8 ft. from the driver by a projector located on the top of the vehicle, while a rearward picture was projected from a projector inside the driver's cabin. Steering inputs were tied to the projector to cause side to side movement of the forward picture. The driver's compartment provided some of the kinesthetic feedback of pitch, yaw and roll. Much of the existing literature about driving simulation is based on research with this device.

The General Motors engineering staff (Beinke and Williams, 1968) developed a driving simulator to study the driver's reaction during emergency situations. A simulated front seat section of the driver's compartment incorporating a moving base (roll and pitch) was used. A single channel forward motion picture projection system featuring a wide-screen color image provided a realistic visual scene to the driver. However, the driver's lateral movement was limited to a small range.

The KAKEN driving simulator of the Traffic Safety Laboratory, Scientific Police Research Institute, Tokyo, Japan (Kobayashi and Matsunaga, 1963) was developed in the same format as the UCLA simulator. For reasons of economy, forward 16-mm film was used; the visual scene covered approximately 50 degrees horizontally. A speed judgement experiment was conducted using this simulator, and the results revealed that the film rate of 24 frames/sec. produced optimal fidelity.

OBJECTIVES

Because motion picture simulators represent an economical and cue-rich visual scene in a driving simulation, it becomes important to determine the limits of application. This research investigation is an attempt to answer questions about these limits of application, with particular emphasis on human psychomotor and vehicle response measures.

In a properly instrumented MPDS, the following display motions may be attained over limited but usable range:

(1) Velocity may be varied over a range that is near the velocity of the camera-bearing vehicle. This is accomplished by changing the projector frame rate.

(2) Vehicle yaw may be varied by moving the projector sideways or "yawing" the projector. Cropping of the frame size tends to aid this illusion of yaw. (Alternatively, a yawing mirror may be used with the projector placed at a right angle to the screen.)

(3) Vehicle pitch may be varied by "pitching" the projector. Again, cropping aids the illusion.

Any combination of the above display motions can be made closed-loop. The driver's control inputs are then applied as inputs to vehicular equations of motion. The outputs of these solved equations are then used to control the display motions. All of this must be done in real-time, without appreciable computational lag. It is nevertheless distinctly feasible to do so at moderate cost.

The motion that cannot be obtained under closed-loop control in an MPDS is lateral translation. Lateral motion requires a complete remapping of every point in the visual scene, except the vanishing point. Motion picture films are not easily re-mapped, and therefore, in general, lateral translation cannot be accomplished. Unfortunately, this is a very important motion in that it is needed when dealing with certain emergency situations, lane changing, and passing.

This thesis has as its goal the determination of the limitations of MPDS systems caused by the lack of lateral translation capability. It also deals with the development of feasible methods for minimizing the effects of a lack of closed-loop lateral translation in MPDS systems. As such, it directly examines and quantifies what is probably the major limitation of MPDS systems.

EXPERIMENTAL METHOD

The VPI & SU computer-generated display driving simulator was used as the central experimental apparatus for this research. A full description of this simulator appears in Wierwille (1973) and in McLane and Wierwille (1975). This simulator possesses a collimated display system that accepts roll, yaw, lateral translation, velocity, and road curvature as inputs, and then produces, at the seated driver's position, roadway and field images that are geometrically correct and non-pupil forming. The simulator also provides three axes of physical motion (roll, yaw, and lateral translation), plus sound and vibration cues.

Because the VPI & SU driving simulator possesses a flexible display system, it can be programmed to simulate a properly instrumented MPDS. In particular, the lateral translation input may be specified as a constant, regardless of the program material. Disconnecting the lateral translation input to the display generation system provides a simulation of a well-instrumented MPDS. Thereby, the full CGDS can be compared with a simulated high-quality MPDS.

The above approach has the advantage of holding all display variables (except lateral translation) constant under comparable conditions. Such an experiment obviously examines the importance of the lateral translation variable. On the other hand, use of the CGDS to simulate an MPDS produces a stylized image that might be likened to desert driving. If an actual motion picture were used, more display variety would be introduced. Whether or not this image variety would affect the measures of performance as used herein is a subject that remains to be investigated.

Preliminary Experiment

Since one objective of this study was to determine the bounds of application of MPDS systems, preliminary experiments were performed to explore these bounds.

The first preliminary experiment dealt with the problem of how best to connect or introduce the lateral translation output of the vehicle dynamics simulation when there is no corresponding display input for lateral translation. Figure 1 shows a block diagram of the lateral directional system of the VPI & SU simulator in its standard (CGDS) mode. (In Figures 1 through 5, curvature and disturbance subprograms are deleted to avoid unnecessary complexity in explanation.) Quite clearly, the entire lateral translation portion of the system could be eliminated in an actual MPDS or in a simulated MPDS. However, to do so would be to create two problems. First, there would be no input signal available for the lateral translation servo. Second, no estimate of any lateral translation measures could be effected, except by indirect means. To avoid these two problems, a different approach was taken, as shown in Figure 2.

Instead of eliminating the lateral translation portion of the system, the lateral translation dynamics output was weighted and then added to the yaw dynamics output. The sum of the two signals was then applied to the yaw input of the display generator. Note that Figure 2 is applicable to an MPDS system and to a CGDS system programmed to simulate an

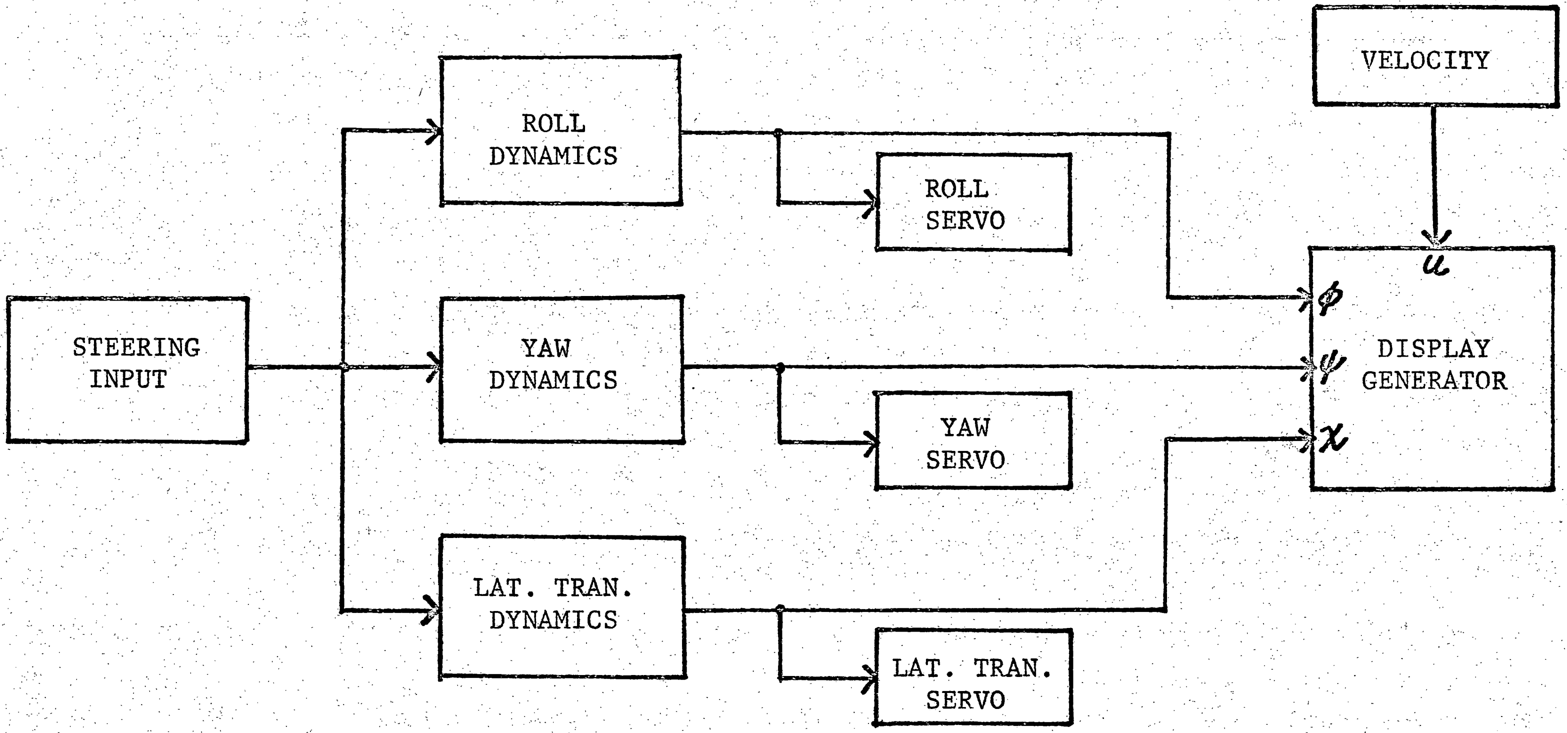


Figure 1. Computer Generated Display Simulater (CGDS): Basic Lateral-Directional System.

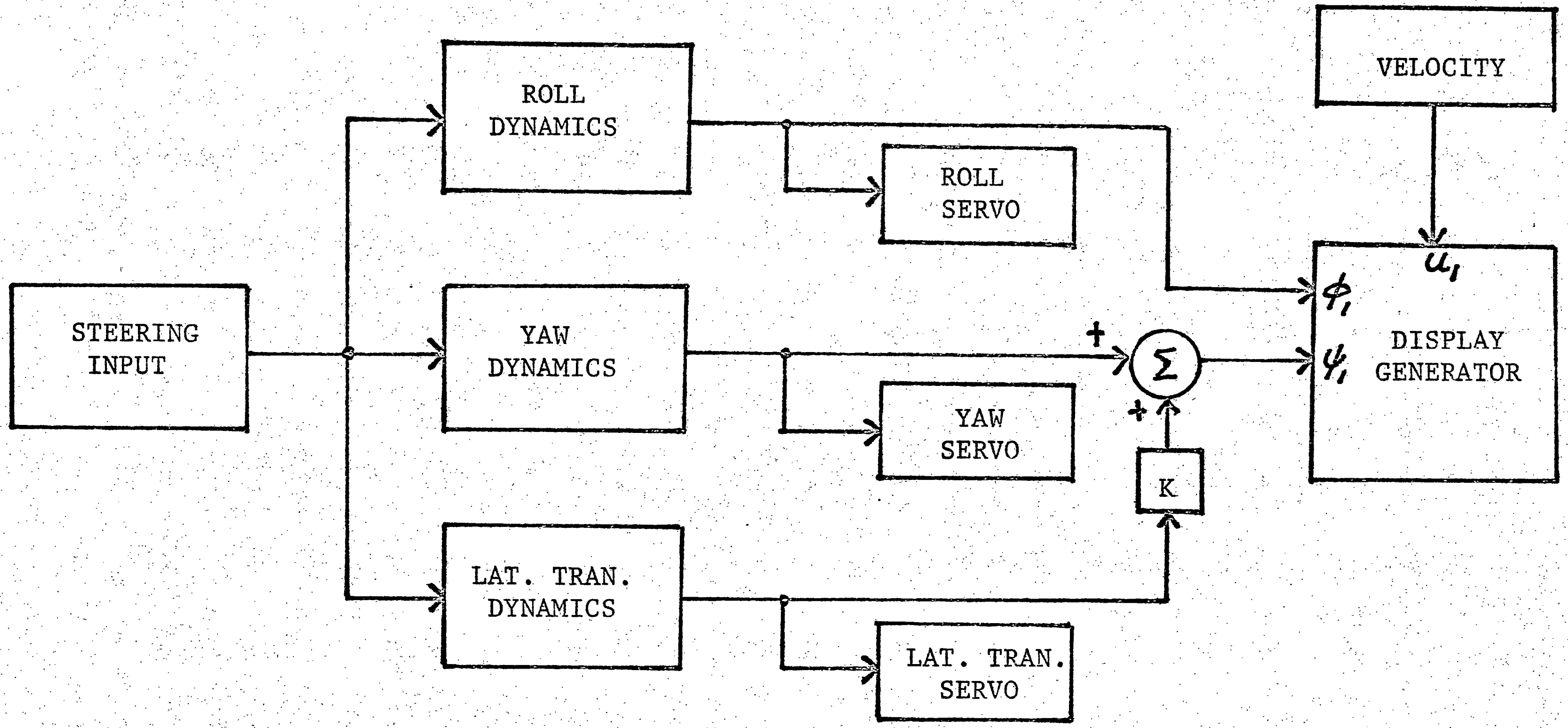


Figure 2. Nonpreprogrammed Motion Picture Display Simulator (MPDS): Basic Lateral-Directional Dynamics.

MPDS system.

Informal preliminary experimental runs using the VPI & SU simulator with this type of system indicated that an optimum range of the weighting constant K does indeed exist. If K is too large, the simulated vehicle becomes difficult to handle primarily because of the swamping of the directional visual cue. If K is too small, the lateral translation output of the dynamics begins to drift and shows large excursions resulting from lack of lateral loop closure. The best setting (again obtained informally) is approximately K = 1.20 deg./ft. To bracket this value on the low side and on the high side, two other values were also selected: K = 0.50; 3.00 deg./ft. All three values of K are definitely within the range of controllability. These three values of K are the ones used as independent variable settings in the later experiments.

The second preliminary experiment had as its objective the development of what might be termed a preprogrammed lane-change procedure in an MPDS. While it is true that lateral translation is not easily obtainable with MPDS systems, it can be obtained in a preprogrammed manner by moving the camera laterally with the picture taking vehicle. Consequently, if the picture taking vehicle performs a lane change maneuver, then the corresponding MPDS will exhibit a lane change in its visual scene. Obviously, if a lane change exists on film, it will take place in the simulator regardless of the driver/subject's responses. Therefore, two experimental procedures must be instituted to make use of a preprogrammed lane change. First, the subject must be instructed to change lanes at precisely the correct time. Second, compensation signals must be introduced into the simulation that force the subject to make the steering wheel motions associated with a lane change. The timing of the instruction to change lanes can be handled by conventional methods, including time markers on the film or detection of a subthreshold tone on the sound track. Accomplishing this is straightforward from a technical standpoint. The timing of the instruction must be advanced sufficiently to allow for subject comprehension and it must be accurate to approximately 1/10 sec.

Figure 3 shows one method of introducing compensating signals for the lane change maneuver in an MPDS. A lane change signal from the display system triggers a "canned" lane change program. This program, in turn, introduces signals in the roll and yaw inputs of the display system. The signals are selected so that if the driver/subject does not apply lane change inputs to the steering wheel, the vehicle appears to yaw and slide sideways. On the other hand, a reasonable attempt on the part of the subject to change lanes results in a smooth and realistic lane change maneuver. (Again, these statements are based on preliminary informal experiments.)

In Figure 3, the purpose of the signal introduced into roll is to avoid doubling of roll motion. If the picture taking camera is rigidly attached to the vehicle, the film will possess roll motion. In simulation, a compensating signal must be applied, since a roll motion input also comes from the simulated roll dynamics. Also in Figure 3, the purpose of the yaw introduced signal is to avoid a similar doubling. However, because of the combining of yaw and lateral translation signals from the simulated vehicle dynamics, the situation is somewhat more complex. Basically, the signal introduced into yaw should make the

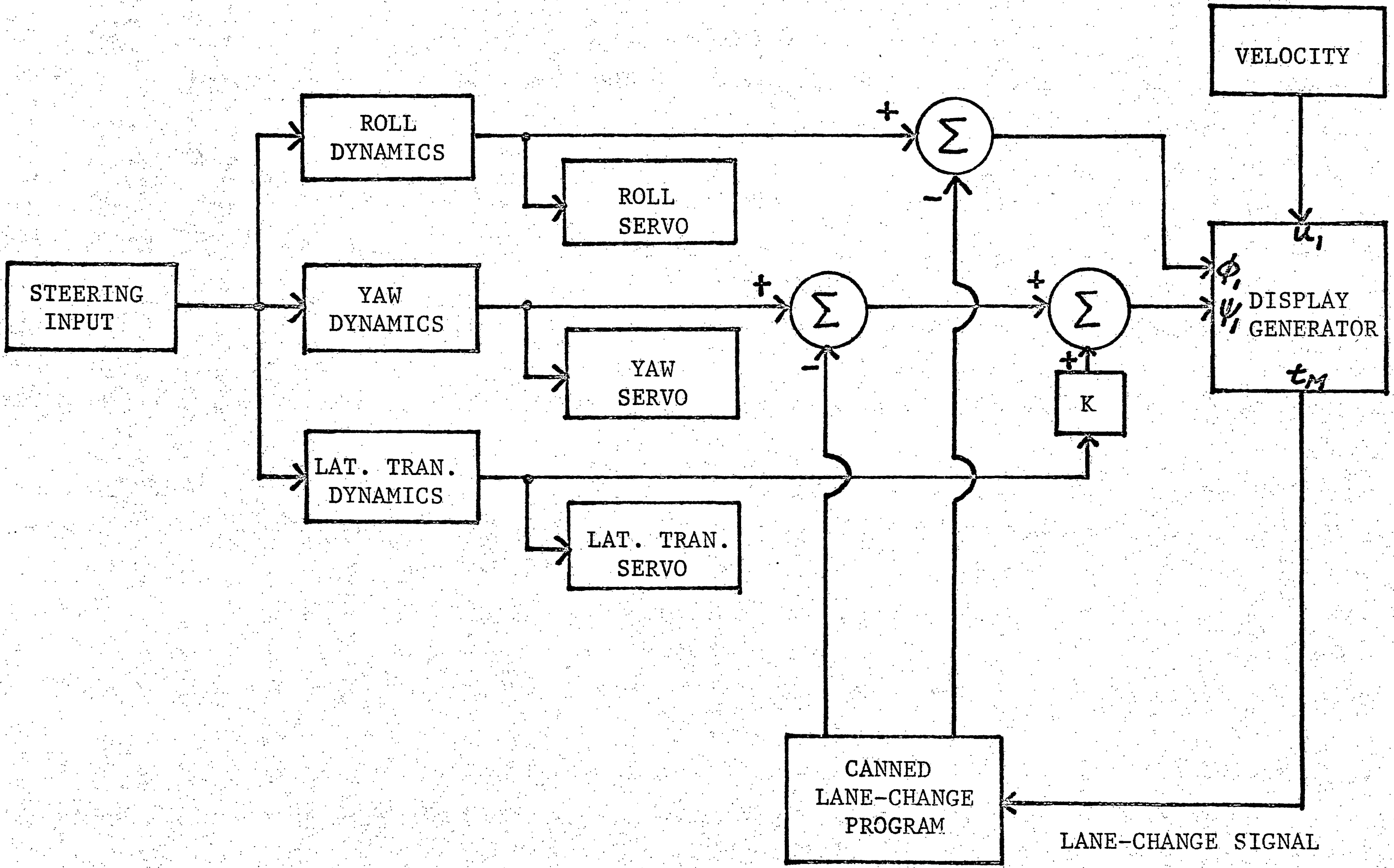


Figure 3. An MPDS Capable of Simulating Preprogrammed Lane Changes.

(yaw) signal into the display system approximately equal to zero for a nominal lane change input on the part of the driver/subject. Here, it must be remembered that the film is preprogrammed for the lane change.

Figure 4 shows how the display portion of a CGDS may be modified to simulate an MPDS with preprogrammed lane changes. The "canned" program inputs to roll and yaw are identical to those used in Figure 3, but the signs for introducing the signals are reversed. Additionally, a "canned" lateral program is required. The overall purpose of the additional equipment in Figure 4 is to produce a nominal lane change of the display, similar to a filmed lane change.

When Figures 3 and 4 are combined, a CGDS simulation of an MPDS with preprogrammed lane changes is obtained. Note, however, that the roll signals compensate for one another. Similarly, the yaw signals compensate for one another. Thus, combining the diagrams of Figures 3 and 4 results in a relatively straightforward CGDS simulation of an MPDS with preprogrammed lane changes, as seen in Figure 5. It is only necessary to provide a "canned" lateral translation input signal in the simulation.

Preliminary experimentation has shown that at 55 mph, a good "canned" signal for the lateral translation input is given by the unit step response of a system having the following transfer function:

$$\underline{G}(S) = \frac{11.5}{(1 + S/10)(1 + 0.715S + S^2)} \qquad (1)$$

where S is the Laplace transform independent variable, and where the numerator is in ft./unit input. The transfer function is applicable

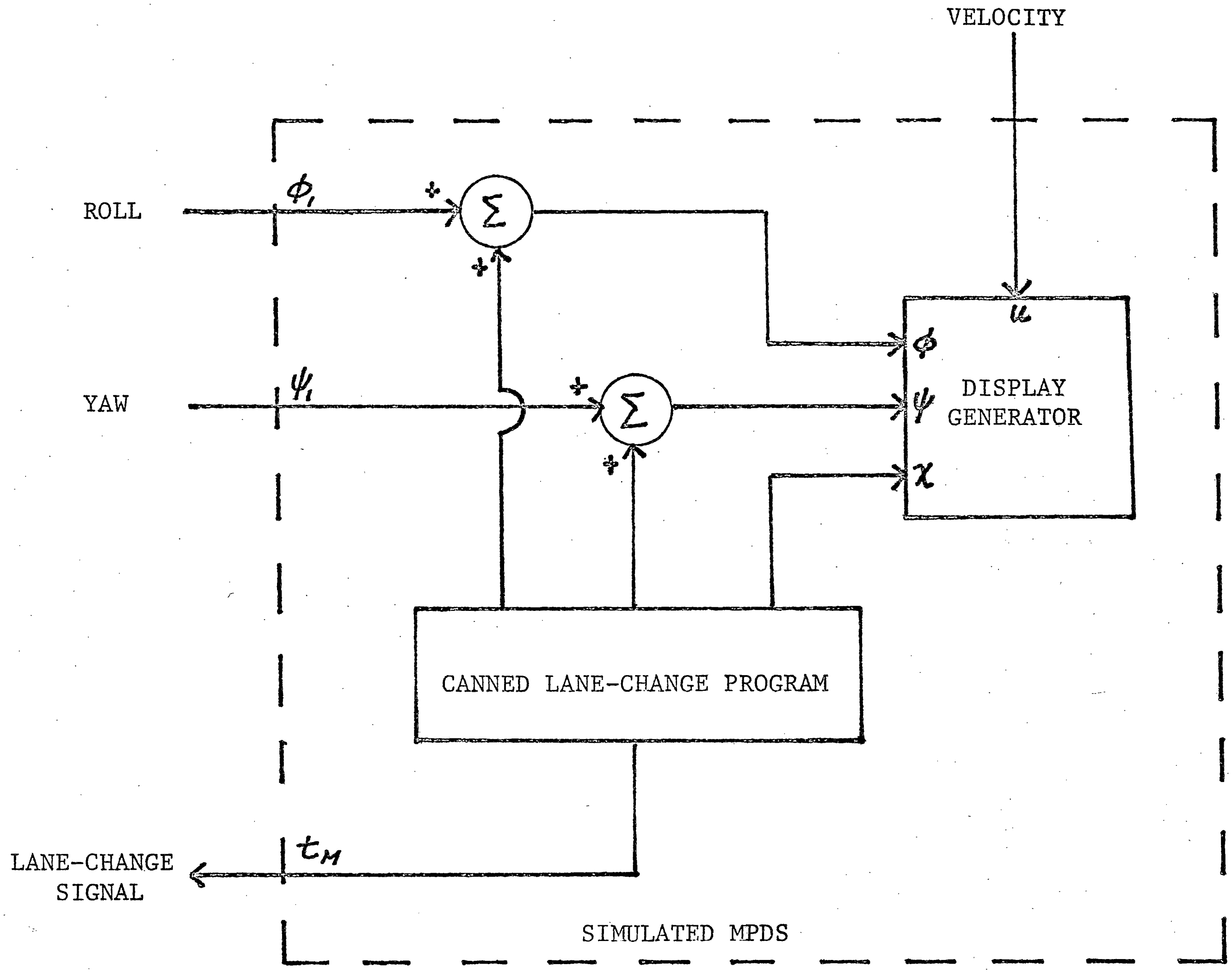


Figure 4. Use of a Computer Generated Display to Simulate a Motion Picture Display with Preprogrammed Lane Changes.

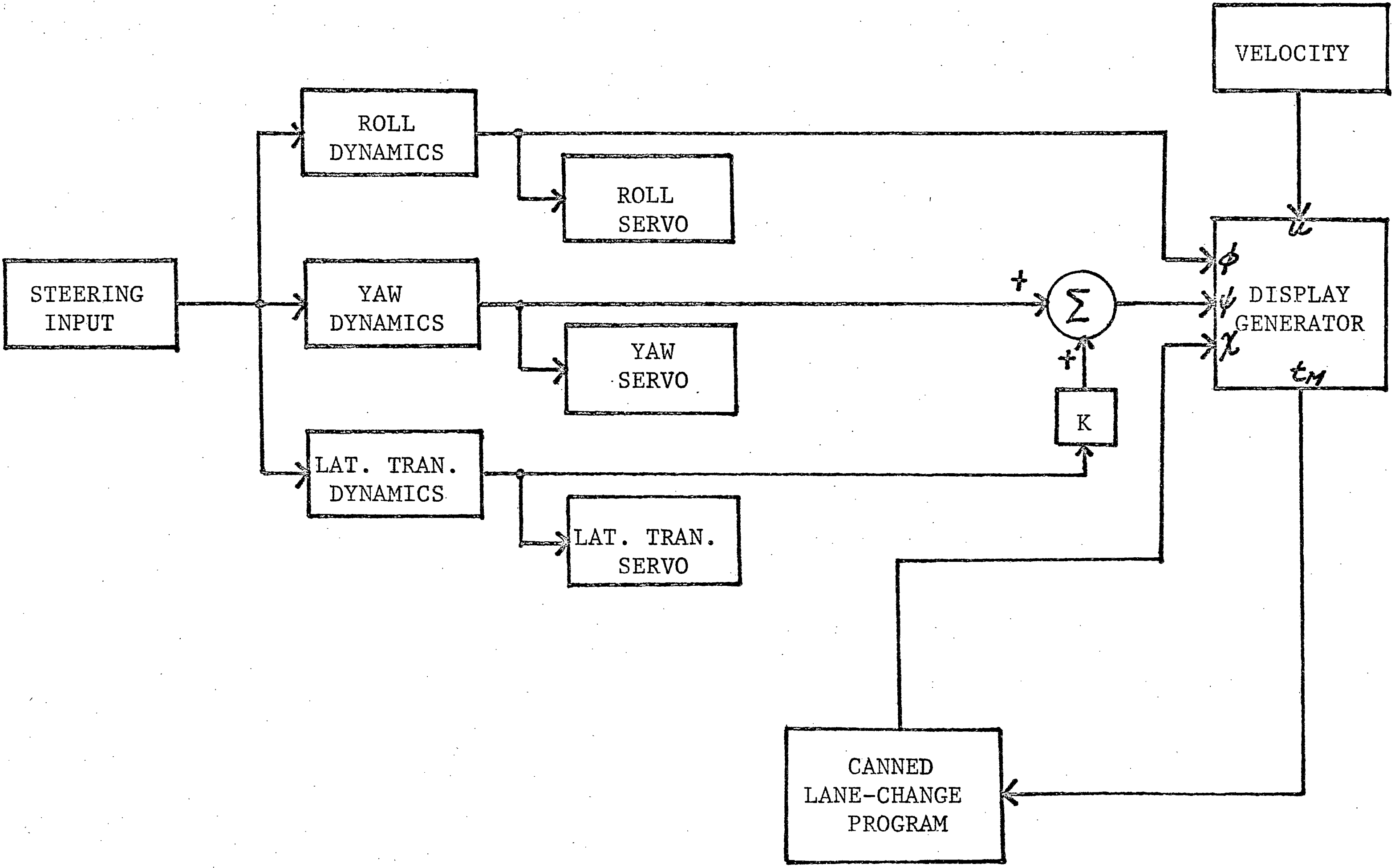


Figure 5. CGDS Simulation of an MPDS with Preprogrammed Lane Changes.

to simulated roadways approximately 12 ft. wide.

It is worth noting here that impressing a unit step on this system produces a transition from the right lane to the left lane. Removing the input produces a symmetrical return to the right lane from the left lane.

The diagram of Figure 5 and the corresponding lane change program were implemented for use in subsequent experiments comparing preprogrammed MPDS lane changes with unprogrammed CGDS lane changes.

Selection of Performance Measures

The driver's role in a driving task is to act as the loop-closure component between the vehicle and the highway. In the language of system analysis, the driver performs input, central-processing, and output operations. According to the nature of the operation, Learner (1969) classified drivers' tasks into three categories: (a) perceptual, (b) intellectual, and (c) psychomotor. These three categories of performance measures have been studied in detail by various investigators.

An automobile driver depends heavily on his vision to supply the necessary environmental information. Yet, the effort of correlating a driver's performance with his visual ability has not been successful (Hulbert and Burg, 1970). The study of driver's perceptual processess has been concentrated on the driver's eye movement superimposed upon the dynamic visual field (Mackworth and Mackworth, 1958). This type of measure has been proven valuable in flight instrument design and may be useful in driving research. However, in obtaining the eye movement data, the presence of eye movement sensing equipment may modify the driver's behavior.

Traditionally, intellectual performance or decision making ability has been measured by "spare mental capacity". This method depends on the assumption that the driver's central information channel and decision making capacity are limited. A secondary task which involves simple logical decision making is usually given to the driver while he is driving. It is assummed that the information inputs of the two tasks are additive. Hence, increasing the difficulty level of one task would result in decreasing performance in another (Brown, 1962; Hilgendorf, 1966). The relevance of this kind of measure is highly questionable, for it has not been proven that mental capacity is significantly correlated with driving performance; rather, the driver's physical condition may constitute a more important factor.

In most of the research dealing with driver behavior, two kinds of response measures are used: driver psychomotor response measures, and driver-vehicle-road system performance measures. In this investigation, performance measure selection was based primarily on the recommendation of recent studies in driver research (Huchinson 1958; Lincke, _et_ _al_., 1973; McLane and Wierwille, 1975). The measures used are described below:

(1) Number of steering reversals. A steering reversal was defined as a deviation of more than 3 deg. from the stationary position.

(2) Number of accelerator reversals. An accelerator reversal was defined as a change in position of the accelerator pedal of more than 0.1 in. from a stationary position.

These two measures alone do not, however, constitute a complete criterion of driving performance as it is normally viewed.

The consequence of using the above two frequency measures in evaluation of driver performance can be seen in Kelley's (1969) work on the measurement of tracking proficiency. He states, "The frequency and amplitude of the signal from the controller forms some index of the effort of the operator in tracking,..." and, "In less tightly constrained control loops, frequency difference between individuals may reflect difference in tracking style" (p. 52). That is, the actual positions of the steering wheel and accelerator pedal are also viable criteria of driving performance; certainly absolute velocity is as important to successful driving as is the steadiness of velocity.

Frequency count types of measures suffer an obvious disadvantage in that they do not furnish the extent of excursion of the variable. To overcome this disadvantage, several alternative variables which measure excursion were used.

(3) Steering wheel deviation. This was defined as the average of standard deviations of the steering wheel position over the entire run where each standard deviation was calculated on a 1-min. sample.

(4) Yaw deviation. The yaw angle is the angle between the nominal straight road axis and the longitudinal vehicle axis. In a curved road, this will be the angle between the tangent of the road curve and the vehicle longitudinal axis. Yaw deviation was defined as the average of standard deviations of the yaw angles of the run, where each standard deviation covered 1-min. of driving time.

(5) Lateral deviation. Lateral deviation was defined as the average of standard deviations of the lateral position in each minute of the experiment.

(6) Velocity deviation. Drivers were instructed to maintain a constant vehicle speed throughout each data run. Velocity deviation was then defined as the standard deviation of the vehicle speed from the instructed speed.

(7) Time in left lane. Subjects were instructed to maintain a right lane position during the run unless lane change signals were given. Time in the left lane was defined as the total time the entire vehicle was within the left lane.

Experimental Conditions

The experiment was designed to compare the CGDS system with the simulated MPDS system. In particular the CGDS system was considered as a control condition. The three values of $\underline{K}$ (the weighting coefficient for introducing lateral translation into the yaw display input) were those determined in the preliminary experiment, viz., $\underline{K}$ = 0.50; 1.20; 3.00 deg./ft. Consequently, these MPDS configurations were compared with the CGDS control condition.

Knowledge of the effect of presence and absence of motion cues in driving simulation is essential to the design and subsequent studies of driving simulators (McLane and Wierwille, 1975). However, research regarding motion effects associated with different types of displays used in simulators has not been performed. Many questions concerning the interaction of motion and driver performance are unanswered. With minor modifications, the VPI & SU driving simulator is able to furnish both motion and no motion driving conditions. Thus, the motion and no motion conditions could be studied in this experiment. Table 1 lists all the experimental conditions used.

Of importance to the driver's information gathering operation are the driving conditions undertaken. The outcome of the driver performance could be altered or become biased if improper driving conditions were selected. In choosing appropriate driving conditions for this experiment, an effort was made to simulate various phases driving conditions which a driver might encounter in normal highway driving. Therefore, the probability of having biased driving conditions was minimized.

It was decided that a 6-min. data run for each subject in each experimental condition should provide sufficient data for evaluation of each driver's performance. In view of the possibility that a driver might not be alert at the beginning of a run, an extra minute of driving time was provided during which no data were gathered. Instructions were given to the driver to perform specific speed changes during this first minute. This was used as a means of insuring that instructions were being heard and understood. The driving conditions and instructions given to the driver are summarized in Table 2.

Eight subjects were used in this experiment, and each subject experienced all eight experimental conditions. Each experimental condition consisted of 14 minutes: the first 7 minutes served as a practice run; the second 7 minutes were for a data collection. The driving conditions given in the first 7 minutes were identical to those

TABLE 1

Experimental Conditions

Experimental Conditions	Motion Cues	Displays
CA	Yes	D_c: Standard CGDS
1A	Yes	D_1: Simulated MPDS, K_1
2A	Yes	D_2: Simulated MPDS, K_2
3A	Yes	D_3: Simulated MPDS, K_3
CB	No	D_c: Standard CGDS
1B	No	D_1: Simulated MPDS, K_1
2B	No	D_2: Simulated MPDS, K_2
3B	No	D_3: Simulated MPDS, K_3

K_1 = 0.50 deg./ft. (0.152 deg./m.)

K_2 = 1.20 deg./ft. (0.366 deg./m.)

K_2 = 3.00 deg./ft. (0.915 deg./m.)

TABLE 2

Driving Conditions

Time (sec)	Vehicle Speed (mph)	Road Condition	Disturbances	Instructions
0-20	40	straight	none	maintain vehicle speed at 40 mph
20-40	75	straight	none	maintain vehicle speed at 75 mph
40-60	55	straight	none	maintain vehicle speed at 55 mph
*60-120	55	straight	none	maintain vehicle speed at 55 mph
120-180	55	straight	random longitudinal and lateral wind gust	none
180-240	55	curved	random longitudinal and lateral wind gust	none
240-300	55	curved	none	none
300-315	55	straight	none	go to the left lane
315-330	55	straight	none	go to the right lane
330-345	55	straight	none	go to the left lane
345-360	55	straight	none	go to the right lane
360-375	55	straight	none	go to the left lane
375-390	55	straight	none	go to the right lane
390-405	55	straight	none	go to the left lane
405-420	55	straight	none	go to the right lane
420	0	straight	none	stop

*Data gathering at 60 seconds.

of the second 7 minutes. To minimize temporal effects (such as gradual learning and fatique) and individual differences, the order of presentation of the experimental conditions was determined by a Latin Square (Myers, 1972). Due to the complexity involved in changing the experimental conditions which have all the motion cues to the experimental conditions which have no motion cues, the Latin Square was broken down into four quadrants such that all experimental conditions belonging to the same quadrant would have the same motion cues. A detailed order of the experimental condition presentation is shown in Table 3, while the complete data matrix is given in Table 4.

Subjects

Eight subjects were recruited from the University student body. Male subjects in the age range from 20 to 24 years were used. Requirements for the subjects were: minimum of two years driving experience, good vision, physically and mentally normal, and having no prior experience with the VPI & SU driving simulator. Appointments were scheduled and subjects were requested to come in "good shape". Subjects were paid $8.00 each.

Data Acquistion

An 8-channel chart recorder (Sanborn 350), a 7-channel FM recorder (Sanborn 2000), and a 16 channel Analog-Digital Data Acquistion System (I.S. Oscar AD-16) were used to collect data for this experiment. The chart recorder receives continuous signals ranging from +5 volts to -5 volts with accuracy within ±0.05 volts. The FM recorder records

TABLE 3

Order of Presentation of Experimental Conditions

Subject	Order of Presentation →							
1	CA	1A	2A	3A	CB	1B	2B	3B
2	2A	CA	3A	1A	CB	2B	1B	3B
3	3A	2A	1A	CA	1B	3B	2B	CB
4	1A	3A	CA	2A	3B	1B	CB	2B
5	3B	1B	2B	CB	3A	1A	CA	2A
6	1B	3B	CB	2B	CA	2A	3A	1A
7	2B	CB	1B	3B	1A	CA	2A	3A
8	CB	2B	3B	1B	2A	3A	1A	CA

TABLE 4

Data Matrix for the Three-Factor, Repeated-Measure Design

		M_A				M_B			
		D_c	D_1	D_2	D_3	D_c	D_1	D_2	D_3
V_1	S_1	Y_{1111}	Y_{1112}	Y_{1113}	Y_{1114}	Y_{2111}	Y_{2112}	Y_{2113}	Y_{2114}
	S_2	Y_{1121}	Y_{1122}	···	Y_{1124}	Y_{2121}	Y_{2122}	···	Y_{2124}
	⋮				⋮	⋮			⋮
	S_8	Y_{1181}	····		Y_{1184}	Y_{2181}	····		Y_{2184}
V_2	S_1	Y_{1211}							
	⋮								
	S_8								
⋮									
V_7									

continuous analog signals on magnetic tape with range ±5 volts and accuracy ±0.05 volts. Most of the analysis of the experiment was based on the data from the Analog-Digital Data Acquistion System (DAS). This 16-channel DAS consists of an analog-to-digital converter and a magnetic tape recorder. Full scale was set at ±5 volts, sample rate was at 125 samples per second, and digitization was carried out to 12 bits. Calibration of each input channel was as follows:

(1) Channel 1 (Steering Angle). Calibration was set at 1 volt = 17 deg. of steering angle. Thus all three recording units were able to record signals within ±85 deg. of the steering input.

(2) Channel 2 (Accelerator Deflection). The up position of the accelerator pedal corresponded to an output of +0.6 volts, and the down position to an output of +7.09 volts. Hence, the difference of 6.49 volts represented 100% of the accelerator range input. Total displacement of the accelerator pedal was 3 in. By offsetting the zero position (so that the maximum output would not exceed 5 volts), the calibration was such that 1 volt = 0.462 in.

(3) Channel 3 (Lateral Gust). Random lateral wind gusts up to 60 mph were applied to the simulated vehicle during each practice and data run. The lateral windgust signal was recorded on the chart recorder and the DAS.

(4) Channel 4 (Longitudinal Gust and Roadway Curvature). Approximate 1.83 miles of simulated curved road (radii of curvature from 0.25 to 1.0 mile) were presented to the driver

in each data and practice run. Random longitudinal windgusts were also introduced. These inputs were added and recorded on this channel.

(5) Channel 5 (Roll). Roll was measured by the angle between the vertical axis of the simulated vehicle and the local vertical axis. Roll angle was recorded at 1 volt = 2.5 deg. with full scale symmetry ±12.5 deg.

(6) Channel 6 (Yaw Angle). Yaw angle was in small amounts and had to be measured with high sensitivity. Therefore, the calibration was set to 1 volt = 1.13 deg. with a full scale of ±5.6 deg.

(7) Channel 7 (Lateral Position). Lateral position of the vehicle was defined as the relative position of the center of the vehicle to the roadway. The roadway display was designed to simulate a two lane highway of width 12 ft. in each lane. Calibration was set to 1 volt = 1.9 ft. Consequently, only when the vehicle was in the center portion of the road (9.5 ft. from either side of the center line), were the recorders able to record its position. Since the simulated vehicle was over 5 ft. wide when the recorders went off scale, an accident or near accident was assummed.

(8) Channel 8 (Velocity). Velocity calibration was set at 1 volt = 10 mph. The recorders were able to record vehicle speed from 0 - 100 mph.

Experimental Procedure

Three operators and a driver were required for the operation of the simulator. The principal operator was stationed at the investigator's console. His duties were to give instructions to and communicate with the subject via the intercom system, to give starting signals to the operator stationed at the TR-48 Analog Computer in the Computer Engineering Laboratory (CEL) via an intercom, to operate the audio system which produced sound effects, to operate the light switches, to operate the hydraulic system, and to monitor any changes in the hydraulic power, oil temperature, motor temperature, and the roadway display shown on the CCTV monitor. One operator was assigned to control the recording equipment (chart recorder and the DAS) as well as the driving conditions given to the driver. He also assisted the principal operator in observing any abnormal events throughout the experiment. Upon receiving signals from the principal operator, the third operator in the CEL had to operate the FM recorder and the Operate-Reset switch of the TR-48 Analog Computer. His duties could be accomplished by someone without detailed knowledge about the experiment.

On the day of data collection, the computers, recording equipment, hydraulic system, and TV monitors were turned on at least one hour before the first experimental run. During this waiting period, potentiometer values of the computers were checked, and a test run of the simulator was conducted. Corrections were made if faults of any kind were detected.

At the commencement of the experiment, the subject was given a set of written instructions (Appendix). After reading the instructions, the subject was directed to the driver's seat. Adjustments of the seat position and safety belt were made, and a final verbal briefing on the safety equipment was presented. After all the questions about the instruments and instructions were answered, lights in the room were turned off, and the first trial run was begun.

The experimental conditions were presented as described in Tables 3 and 4. After every other data run, the subject was given a 3-min. rest while remaining in the simulator. After four data runs, however, (the halfway point) the subject was instructed to leave the simulator and take a 10-min. rest. During this 10-min. break, simulator motion was either removed or reinstated (according to Table 3) and an operational check of all simulator systems was made.

Data Reduction

Data recorded on the Data Acquisition System were in 12-bit form. A conversion program was devised to convert the binary numbers into decimal form. The original data were sampled at the rate of 125 times per second, an unnecessarily high rate for the measures used. Therefore, the decimal data were fed into a second program which reduced the number of samples by a factor of 10 (simply by taking every tenth sample) and stored them on a master data tape.

As mentioned earlier, each data record was six minutes in length. In the first four minutes, the subject drove only in the right lane; in the last two minutes, the driver was instructed to make lane changes. The first four minutes were used to compute all performance measures except the last one, time in left lane. The last two minutes were used to compute only the time in left lane measure.

When the data were transformed to decimal form, the upper limit for the data was $2^{11} = 2048$ and the lower limit was $-2^{11} = -2048$. Since the DAS was set to receive signals from 5 volts to -5 volts, it followed that 5 volts = $2^{11} = 2048$ decimal units. Hence, in the decimal data, the reading of 410 units was equivalent to 1 volt of analog input.

Computional procedures of each variable, its conversion factor (from decimal units to driver's physical output and vice versa), and brief description of the data are given below:

Steering Reversals. 410 units = 1 volt = 17 deg., or 1 deg. = 24 units. Number of steering reversals was defined as the number of times that the steering wheel was turned more than three degrees from the stationary position. A computer program was developed to detect changes of the decimal data (from local maxima to local minima) that were greater than 72 units (3 x 24). The number of steering reversals could then be easily tallied. The data obtained for the 4-min. run ranged from 44 (subject 2, condition 1A) to 165 times (subject 8, condition 3B) with mean 78.33 and standard deviation 26.94.

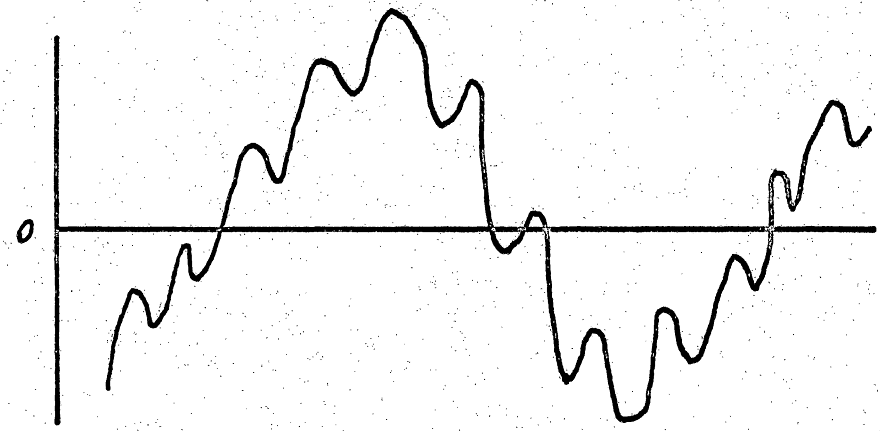
Accelerator Reversals. 410 units = 1 volt = 0.462 inch or 1 inch = 886 units. Number of accelerator reversals was defined as the total number of times that the accelerator pedal was deflected more than 0.1 in. from a static position. The computer program used to extract number of steering reversals from the decimal data was also applicable here (the sensitivity was adjusted to 89 units). The data obtained for the 4-min. run ranged from 3 (subject 1, condition CA) to 44 times (subject 8, condition 2A) with mean 12.05 and standard deviation 11.15.

Steering Wheel Deviation. 1 deg. = 24 units. Simulated straight and curved road conditions were given to the driver. Consequently, in measuring the steering wheel deviation, the inherent curvature in the steering position should be deleted. A digital high-pass filter subprogram was developed for this purpose. Figure 6 provides a visual interpretation of how the filter transformed the input data. After the filtering, the data were broken into four 1-min. blocks and fed into the main program to compute the standard deviation for each block of data. The mean of these four standard deviations was the steering wheel deviation. The data obtained for the 4-min. run ranged from 337.46 units (subject 5, condition 1A) to 1063.86 units (subject 1, condition CB) with mean 493.63 units and standard deviation 135.72 units.

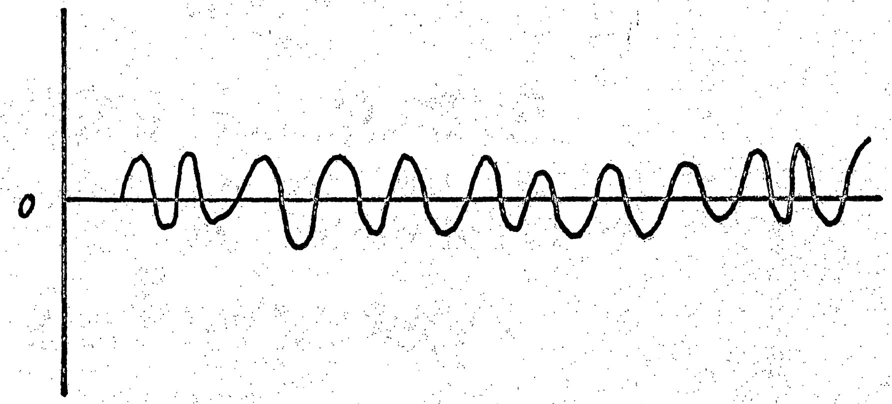
Yaw deviation. 410 units = 1 volt = 1.13 deg. or 1 deg. = 363 units. Decimal data for the yaw angle were divided into four 1-min. blocks. The standard deviation of each block of data was then computed. The average of the four standard deviations was the desired yaw deviation. The yaw deviation obtained ranged from 379.65 (subject 5, condition 3A) to 1266.69 units (subject 3, condition 1A) with mean 792.34, standard deviation 207.58.

Lateral Deviation. 410 units = 1 volt = 1.9 ft., or 1 ft. = 216 units. Lateral deviation was obtained in the same manner as yaw deviation. The data ranged from 350.63 (subject 5, condition 3A) to 2232.57 units (subject 6, condition 1A) with mean 1128.47, standard deviation 604.12 units.

Velocity Deviation. 410 units = 1 volt = 10 mph, or 1 mph = 41



(a) Before Transformation



(b) After Transformation

Figure 6. Transformation of Data by a Digital High Pass Filter.

units. Velocity deviation was also obtained in the same manner as yaw deviation. The data ranged from 883.39 (subject 2, condition 1A) to 368.59 units (subject 4, condition CA) with mean 162.83, standard deviation 68.82 units.

Time in Left Lane. Margins were set on both sides of the left lane $3\frac{1}{2}$ feet from center. Drivers were instructed to go to the left lane (and return) twice during the fifth minute of the data run and twice during the sixth minute. The total time in which the vehicle center fell within the above margins was recorded. For simulated MPDS conditions (1A, 2A, 3A, 1B, 2B, 3B), the lane changes in the fifth minute were preprogrammed using the "canned" procedure described earlier. The data of the fifth minute were then used to compare the preprogrammed MPDS with the CGDS. During the sixth minute the "canned" procedure was not executed even though the subject was instructed to change lanes. The purpose of the data taken during the sixth minute was to allow comparison of attempted MPDS lane changes (without preprogramming) and CGDS lane changes. The data of the sixth minute were treated in a separate analysis. For the fifth minute, the total time in left lane bracket ranged from 7.2 seconds (subject 6, condition 1A) to 30.5 seconds (subject 3, condition 3A and subject 6, condition 3B) with mean 23.14 seconds and standard deviation 5.6 seconds. For the sixth minute, the data ranged from zero seconds (subject 5, condition 2A and 3A) to 24.5 seconds with mean 12.21 seconds, standard deviation 11.01 seconds.

Normalization of Data

The performance measures obtained from the experiment were of several different types (see discussions in Selection of Performance Measures and also Data Reduction). In order to make sensible comparisons between the CGDS and the preprogrammed MPDS, data of each measure (subscript k) were transformed to Z scores according to the following formula:

$$Z_{ijk} = \frac{Y_{ijk} - \bar{Y}_k}{\sigma_k} \qquad (2)$$

where Y_{ijk} was the raw score of the i^{th} subject for condition j. $\bar{Y}_k$ was the mean of all raw scores for variable k; and σ_k was the standard deviation of all raw scores for variable k. After normalization, the sum of all scores for each measure was zero and the variance was approximately unity.

RESULTS

Three-Way Analysis of Variance

The transformed scores constituted a repeated measure three-way analysis model with two levels of motion, four levels of displays, and seven dependent variables. The UCLA Biomedical Computer Program (1973) entitled Analysis of Variance for Factorial Design was used to analyze the data. Results of the three-way analysis are summarized in Table 5. The analysis of variance indicates that the only significant effect is the interaction between displays and the dependent variables. In order to better examine this interaction, the measures of each D x V combination were tabulated as shown in Table 6. The table shows that there are distinct trends in several of the performance measures at the three different levels of $\underline{K}$ (D_1 through D_3).

Comparison of Displays under Individual Measures

A separate analysis of variance with four levels of displays was performed on each dependent variable. Tables 7 through 13 summarize the results of these analyses. As the tables show, significant differences were found in steering reversals, steering deviation, yaw deviation, lateral deviation, and time in left lane (all at $\underline{p} < .001$). Accelerator reversals and velocity deviation were not significant ($\underline{p} > .05$).

To examine more closely the loci of significance, Dunnett's (1955) test for comparing several treatments with a control was employed on each of the five lateral directional measures showing significance. In this case, the CGDS is used as the control condition and each MPDS with a given level of K is used as a comparison condition. Tables 14 through 18 show the results of these tests for each of the five measures.

With K = 0.50 deg./ft., all five measures are significantly different from the control (CGDS). Also, with K = 3.00 deg./ft., four of the five measures are significantly different from the control. In contrast, with K = 1.20 deg./ft., none of the five measures is significantly different from the control. These results are summarized in Table 19.

Analysis of Results for Nonpreprogrammed MPDS Systems

Data taken during the sixth (last) minute of each run were used to compare lane change performance using a CGDS with lane change performance using the preprogrammed MPDS configurations. Time in left lane (as defined earlier) was used as the performance measure. Table 20 shows the mean data for this part of the experiment. An analysis of variance (Table 21) reveals significance ($p < .001$) of the display variable. Again, applying Dunnett's (1955) test (Table 22) with the CGDS measure values used as control, it is seen that all three nonpreprogrammed MPDS displays are significantly different from the control.

TABLE 5

Analysis of Variance Summary.

Source of Variance	df	MS	F
Motions (M)	1	2.128	2.056
Variables (V)	6	0.000	0.000
Displays (D)	3	0.702	1.053
Subjects (S)	7	4.404	
M x V	6	0.438	1.003
M x S	7	1.035	
M x D	3	0.410	1.258
V x S	42	3.347	
V x D	18	8.142	23.527*
D x S	21	0.666	
M x V x S	42	0.437	
M x V x D	18	0.231	
M x D x S	21	0.326	
V x D x S	126	0.346	
M x V x D x S	126	0.220	
Total	447		

*$p < .001$

TABLE 6

Mean Values of the Displays x Variables Combinations.

Variables	D_c	D_1	D_2	D_3
Steering Reversals	80.500	62.938	74.438	95.437
Steering Deviation	490.114	397.852	467.941	618.618
Accelerator Reversals	11.000	10.500	15.563	11.126
Yaw Deviation	802.343	997.102	726.946	642.978
Lateral Deviation	951.072	1983.686	991.779	587.258
Velocity Deviation	172.685	158.149	157.465	163.022
Time in Left Lane	26.282	15.794	24.319	26.182
$\overline{D}_i$	362.000	518.003	351.208	306.375

TABLE 7

Analysis of Variance of Steering Reversals with Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	4.038	12.527*
Subjects (S)	7	5.414	
D x S	21	0.322	
Total	31		

*$p < .001$

TABLE 8

Analysis of Variance of Steering Deviation With Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	7.374	15.858*
Subjects (S)	7	3.196	
D x S	21	0.465	
Total	31		

*$p < .001$

TABLE 9

Analysis of Variance of Accelerator Reversals with Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	0.717	2.129
Subjects (S)	7	7.159	
D x S	21	0.336	
Total	31		

TABLE 10

Analysis of Variance of Yaw Deviation with Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	8.492	18.788*
Subjects (S)	7	2.338	
D x S	21	0.452	
Total	31		

*$p < .001$

TABLE 11

Analysis of Variance of Lateral Deviation with Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	15.702	51.456*
Subjects (S)	7	0.739	
D x S	21	0.294	
Total	31		

*$p < .001$

TABLE 12

Analysis of Variance of Velocity Deviation With Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	0.163	0.458
Subjects (S)	7	6.822	
D x S	21	0.357	
Total	31		

TABLE 13

Analysis of Variance of Time in Left Lane Bracket with Four Levels of Displays

Source of Variance	df	MS	F
Displays (D)	3	12.620	26.185*
Subjects (S)	7	0.168	
D x S	21	0.569	
Total	31		

*$p < .001$

TABLE 14

Results of Dunnett's Test for Comparing Number of Steering Reversals in Three Levels of MPDS with a Control (CGDS).

D_C vs.	D_1	D_2	D_3
CONTROL	$T_D = 3.750$*	$T_D = 1.294$	$T_D = 3.189$*

*$p < .05$

TABLE 15

Results of Dunnett's Test for Comparing Steering Deviation in Three Levels of MPDS with a Control (CGDS).

D_C vs.	D_1	D_2	D_3
CONTROL	$T_D = 3.254^*$	$T_D = 0.783$	$T_D = 4.535^{**}$

$^*p < .05$
$^{**}p < .01$

TABLE 16

Dunnett's Test for Comparing Yaw Deviation in Three Levels of MPDS with a Control (CGDS).

D_C vs.	$\underline{D}_1$	$\underline{D}_2$	$\underline{D}_3$
CONTROL	$T_D = 4.559^{**}$	$T_D = 1.763$	$T_D = 3.728^{*}$

$^{*}\underline{p} < .05$
$^{**}\underline{p} < .01$

TABLE 17

Dunnett's Test for Comparing Lateral Deviation in Three Levels of MPDS with a Control (CGDS).

D_C vs.	$\underline{D}_{\underline{1}}$	$\underline{D}_{\underline{2}}$	$\underline{D}_{\underline{3}}$
CONTROL	$T_D = 10.301^{**}$	$T_D = 0.407$	$T_D = 3.632^{*}$

$^{*}\underline{p} < .05$
$^{**}\underline{p} < .01$

TABLE 18

Dunnett's Test for Comparing Time in Left Lane Bracket in Three Levels of MPDS with a Control (CGDS).

D_C vs.	D_1	D_2	D_3
CONTROL	$T_D = 8.096$*	$T_D = 1.515$	$T_D = 0.078$

*$p < .01$

TABLE 19

Summary of Results from Dunnett's Tests on Individual Variables.

Variables D_C vs.	D_1	D_2	D_3
Steering Reversals	Sig:	N.S.	Sig:
Steering Deviation	Sig:	N.S.	Sig:
Yaw Deviation	Sig:	N.S.	Sig:
Lateral Deviation	Sig:	N.S.	Sig:
Time in Left Lane	Sig:	N.S.	N.S.

Sig: Significantly different from the control (CGDS) ($p < .05$)
N.S. Not significantly different from control ($p > .05$)

TABLE 20

Time in the Left Lane (sec.).

	CONDITIONS							
SUBJECT	CA	1A	2A	3A	CB	1B	2B	3B
1	29.0	4.5	4.0	3.4	29.5	11.2	7.8	8.2
2	28.9	12.0	7.0	0.0	28.1	9.3	4.0	8.0
3	29.0	2.9	3.0	21.8	25.2	1.2	3.1	21.5
4	28.8	2.1	5.7	25.5	29.5	1.4	2.0	8.0
5	23.5	19.5	0.0	0.0	24.5	29.0	2.8	1.2
6	26.0	1.7	1.2	1.6	28.8	0.3	0.2	3.0
7	26.5	4.5	16.0	3.2	28.5	5.5	5.3	10.2
8	27.7	1.2	1.8	20.5	27.0	0.2	5.5	23.0

TABLE 21

Analysis of Variance of Total Time in Left Lane Bracket for Four Types of Display Conditions.

Source of Variance	df	MS	F
Displays (D)	3	1774.20	19.02*
Subjects (S)	7	25.58	
D x S	21	93.27	
Total	31		

*$p < .001$

TABLE 22

Dunnett's Test for Comparing Time in Left Lane of Three Levels of MPDS with a Control (CGDS); Lane Change Preprogramming Deleted.

D_C vs.	$\underline{D_1}$	$\underline{D_2}$	$\underline{D_3}$
CONTROL	$T_D = 5.418^*$	$T_D = 6.736^*$	$T_D = 5.195^*$

*$\underline{p} < .01$

CONCLUSIONS AND RECOMMENDATIONS

The statistical analyses performed on the data demonstrate that the lack of lateral translation in a display generating system need not cause significant changes in driver and driver/vehicle performance measures in a driving simulation. Since MPDS systems lack lateral translation, this finding is important.

The three-way analysis of variance showed that there is a strong interaction between dependent variables and display conditions. Consequently, improper implementation of an MPDS is likely to cause performance to differ from that of a CGDS or other system capable of closed-loop lateral translation. Display condition _per se_ was not significant, but this can be attributed to counterbalancing increases and decreases across performance measures, as seen in Table 6.

Analysis of variance of the CGDS and three MPDS conditions for each of the seven measures showed that all measures associated with the lateral-directional man-machine system were significant. The longitudinal measures, on the other hand, were not. These results can be attributed to the idea that presence or absence of lateral translation does not affect the ability to estimate forward velocity.

The summary of Dunnett's Test results in Table 19, performed on the lateral directional measures, shows that MPDS condition $\underline{D}_2$ ($\underline{K}$ = 1.20 deg./ft. does not differ significantly from the CGDS for any of the lateral directional measures. The other two conditions, $\underline{D}_1$ and $\underline{D}_3$ differ significantly in nine out of ten total measures. The summary indicates that the tests performed were sensitive to the parameter K, and that this parameter should be properly set in any MPDS; this is, it should possess a value of 1.20 deg./ft.

Returning to Table 6, it is observed that the seven measures of the MPDS with K = 1.20 deg./ft. (D_2) bear strong resemblance to the CGDS. Consequently, the effects of lack of lateral translation can be overcome for a wide variety of performance measures provided proper instrumentation and instructions are used.

The above statement applies to both the lane keeping task and to the lane changing task. In lane keeping, the subject must be instructed to remain in the lane. Compensating signals must be applied whenever road curvature occurs. These are necessary to offset the driver's inputs.

In the lane changing task, the film itself must contain a lane change. A properly instrumented "canned" program must be used to require the driver to make the necessary steering inputs to change lanes. The driver must be instructed at the correct time to perform the lane change.

Tables 20, 21, and 22 show that an MPDS cannot produce performance in lane changes similar to a CGDS unless adequate preprogramming is used. More specifically, if a "canned" program is not used, lane change time brackets will be significantly affected regardless of the selection of the parameter K.

Returning once again to Table 5, it is observed that the motion effect was not significant in this experiment at the $p < .05$ level. However, a trend does exist. Differences in motion effects between this study and the study of McLane and Wierwille (1975) could be the result of different experimental designs. In this experiment, a repeated-measure factorial design was employed. Each subject experienced the motion and no-motion conditions. In McLane and Wierwille's (1975) experiment, a randomized design was used. Each subject experienced only one motion condition so as to minimize the gradual learning and synthesis effects.

In the preliminary experiments it was found that realistic lane keeping and lane changing tasks could be accomplished by proper programming, even though no close-loop lateral translation was available in the display. In fact, for the $\underline{D}_2$ condition, the investigators had difficulty distinguishing it from the CGDS condition. The subsequent experiments showed that performance measures do not differ significantly between the MPDS-D_2 condition and the CGDS condition.

On the basis of all experiments performed, the following simulator design recommendations are made:

1. A driving simulator incapable of closed-loop lateral translation in the display should be instrumented as shown in Figure 2 for lane keeping tasks. The constant $\underline{K}$ should be set at 1.20 deg./ft.
2. If lane changing tasks are desired, the simulator should be instrumented as shown in Figure 3. In this case, lane changes must occur on film (or other fixed medium), and instructions must be carefully timed to insure synchrony.
3. The simulator should be designed for closed-loop velocity, yaw, and roll control, if performance measures such as those

used in this experiment are to be recorded and analyzed.

Finally, the results show that careful attention must be given the overall design of an MPDS simulator, if it is to function near its maximum inherent capability.

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APPENDIX

Written Instructions Given to the Subjects

Instructions

You are about to participate in a group of driving simulator experiments. The purpose of these experiments is to make possible the comparison of different settings of simulator design parameters.

You will be seated in the driver's position of an automotive mock-up. You will be presented with a visual display consisting of a moving, geometrical roadway simulation, and a dashboard speedometer. During operation of the simulator, you will experience simulated vehicle motions (during some of the runs) corresponding to the driving conditions and your control maneuvers. Your control of the simulator's speed and road position will be by means of a standard steering wheel and accelerator pedal as in a normal automotive configuration. After being seated on the platform you will be given instructions by, and may communicate with the experimenter via the dash mounted (upper right) speaker/microphone.

The total experiment will take approximately 2 ½ hours to complete. It will be broken into 6 minute runs. First a practice run will be made; a data run will then follow. Subsequently, the parameters of the simulator will be adjusted, and another practice and data run will be taken. In other words, practice and data runs will alternate, with adjustments in the simulator after each data run.

Some of the simulator conditions may feel quite strange to you, while others seem rather normal. In all cases, attempt to drive as you usually would on a highway. As you perform the instructed tasks please keep in mind that normal driving behavior is expected from you.

During each run, you will be asked to perform three types of tasks:

1. Maintain normal right lane position
2. Make a speed change.
3. Move to the left lane, or move back to the right lane.

The experimental procedure will be as follows:

1. Be seated in driver's seat; adjust seat position and fasten safety belt.
2. Become familiar with controls, speaker/microphone, and emergency motion cut-off button.

NOTE: Activation (1 push) of the emergency motion cut-off button halts all motion of the simulator platform. If at any time during the experiment you sincerely feel that continued simulator operation would not be agreeable with you, please verbally notify the experimenter and depress (once), the emergency motion cut-off button. You may leave the platform (to the left only) if and only if all platform motion has stopped.

3. Communications checkout and questions.
4. Begin with the first practice run.

The personnel working on this project greatly appreciate your help. You will be instructed on how to receive payment.

COMPARISON OF A COMPUTER GENERATED DISPLAY AND A SIMULATED MOTION PICTURE DISPLAY IN DRIVING SIMULATION

by

Peter P. Fung

(ABSTRACT)

An automotive driving simulator with a computer generated display system, three axes of physical motion (roll, yaw, and lateral translation), sound, and vibration cues was used to investigate and compare human psychomotor response and vehicle response to different types of displays and motion cues. Eight subjects were instructed to "drive" the simulator under three levels of simulated preprogrammed motion picture display (MPDS) and the standard computer generated display (CGDS). Motion and no motion conditions were instituted at each level of display. A 6-minute data run was obtained for each possible combination of display and motion condition and for each subject. The first four minutes consisted of a lane keeping task under combinations of simulated straight road, curved road, and lateral and longitudinal wind gust conditions. In the fifth and sixth minute, subjects were instructed to perform lane change maneuvers. However, in the fifth minute, the simulator was preprogrammed for lane change maneuvers involving MPDS conditions, whereas in the sixth minute, it was not preprogrammed. Seven dependent variables were used to measure performance.

Results of the experiment show that one level of the simulated preprogrammed MPDS produced performance similar to that of a CGDS in all seven measures, whereas the other levels differ significantly. This suggests that using a properly instrumented preprogrammed MPDS will not compromise experimental results for certain research and educational experiments.

The sixth minute of the data run in the experiment was designed to compare the CGDS with the simulated nonpreprogrammed MPDS. The results revealed that the nonpreprogrammed MPDS cannot produce performance in lane change similar to the CGDS.