# THE MEASUREMENT AND COMPARISON OF RELATIVE WORKLOADS UNDER SEVERAL DRIVING CONDITIONS USING A SIMULATOR

by

Florus Gerhardt Gross

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:

W. W. Wierwille
W. W. Wierwille, Chairman

HL Snyder
H. L. Snyder

D L Price
D. L. Price

February, 1977

Blacksburg, Virginia

# ACKNOWLEDGEMENTS

The author feels it appropriate to thank a number of people for their help and encouragement during this rather long ordeal. Between working full-time for five years and finally writing this thesis it has taken nearly seven years to complete this degree. My wife, Cynthia, has been supportive and long-suffering throughout this period, and I thank her for this support.

Dr. Walter W. Wierwille deserves a great deal of thanks for his guidance in the research for the thesis. His help in the physical and statistical design has made the results possible. Thanks are also due Dr. Harry L. Snyder and Dr. Dennis L. Price for their support throughout the research and thesis preparation.

Special thanks are due William Muto for his constant assistance in preparing the experimental conditions, preparing the simulator and, above all, for his time and help in running the simulator for over eighty subjects. The latter could not have been done alone. I also wish to thank John Evans for his help in the data analysis. General Motors Corporation must be thanked for providing the research money that has made this study, as well as others, possible over the last three years. Lastly, I must thank Mrs. Bernie Curtis for her efforts in typing the thesis and in its general preparation.

# TABLE OF CONTENTS

Page

# LIST OF TABLES

# LIST OF FIGURES

# INTRODUCTION

Simulators of many types have been used for many years and for many purposes. They have been used for the design of airplane cockpits, for the design of dashboards in cars and other vehicles, and for training purposes in many types of vehicles. In each of these situations it is easier and cheaper to use a simulator or possibly a mockup of the design. In the design stage of any project, the simulator can be used to study a number of possible configurations without the time and expense of full-scale production. In the case of aircraft, cars, ships, *etc*, both the expense and the dangers are reduced to tolerable levels.

## *Purpose*

The research for this thesis had two objectives. The first was the development and refinement of a measure of workload that is sensitive to changes in the difficulty of the automobile driving task. The second was to determine the changes in workload as a function of changes in the simulated vehicle handling parameters. It was intended that the measure be useable in driving simulators and that it be transferable to on-the-road vehicles under real-world conditions. A measure of this type would be very useful for evaluating current production vehicles and also for evaluating new, even radical, designs via simulators without the time and expense of building vehicles for road or track testing.

## *Workload*

The total workload of any task consists of, and is affected by, many factors. In the driving task one must control lane position, speed, and relative distance to other vehicles and obstacles. The workload involved in these control processes is affected by such things as vehicle speed, traffic congestion, lane width, weather conditions, vehicle handling parameters, distractions within the vehicle, lighting conditions, *etc*. With all of these factors involved in driver workload it is necessary to control as many of these factors as possible. By controlling the test environment, factors that are to be tested can be varied and the remaining factors, by being constant, will not confound the workload results. The best way to do this is to use a simulator.

The workload measurement technique must be one that can easily be used and yet is sensitive to the changes in workload. Knowles (1963) has described one such technique using an operator loading task. An operator loading task is one that is performed concurrently with the primary task that is being evaluated. The performance of the loading or "secondary" task as compared with the performance on that task when performed alone, gives an indication of the workload of the primary task. Senders (DeGreene, 1970, p. 208) indicates that in using this methodology some basic assumptions must be made:

1. The operator is a single-channel system.
2. The channel has a fixed capacity.
3. The capacity has a single metric by which any task can be measured.
4. The constituents of workload are additive linearly, regardless of the source of the workload.

The assumption that the operator is a single-channel system implies that the operator can process only one stimulus input at a time. If two or more stimuli are present, they must time share the single channel. Channel capacity is discussed in two respects. Channel capacity refers to the capacity of a communication channel. The broader concept relates to an upper limit of information that can be received and processed by a subject per unit of time. Workload theory makes use of this upper limit as a base for measuring the workload of the primary task. The single metric assumption allows the addition or subtraction of workload scores with no conversions being necessary. The final assumption follows from the others.

Given the above theory and assumptions it becomes apparent that the operator must schedule his time to perform the primary task within some set of instructed criteria and respond to the secondary task only in his "spare" time. The secondary task must not interfere with the primary task. The secondary task must be simple, easy to learn and perform, and continuous. The stimuli presented to the subjects are usually of a discrete nature, but close enough so that the task can be considered to be continuous. The word continuous is important here because it is necessary that the secondary task be capable of commanding 100% attention from the subject so that a base can be established for comparison.

There are many possible stimulus/response combinations. In selecting a secondary task to be used with the primary task of driving, it was felt that a visual stimulus to the subject and a verbal response would be a compatible combination. This would leave the subject's hands free to perform the driving task and also would allow the subject to remain in a relatively constant position in the simulator, rather than being forced to reach for some response device.

The secondary task consisted of the subject reading and calling out single digit random numbers. The presentation rate was adjusted for each subject to require 100% attention. From previous studies by McDonald (1973) and Price (1975), it was expected that the presentation rate would be between two and four digits per sec. (The majority of subjects in this study were capable of 2.5 digits per sec.)

### *Test Environment*

Testing in on-the-road vehicles on an open highway provides the maximum realism for any vehicle or driver testing. Open road stimuli, however, are hard to control. The lack of control may make data interpretation difficult and may cause conclusions to be drawn that cannot be supported by other studies. A closed road course allows better control of the stimuli presented to the subjects. This will keep the environment consistent for all of the subjects, but learning effects may appear because the subjects drive the same course several times. The third alternative is a driving simulator. A simulator allows the best control of stimuli and can minimize learning effects by providing a non-repeating roadway. Unfortunately, the lack of fidelity in (many) simulators may cast doubts on the conclusions drawn from them. Therefore, before any simulator can be put to practical use, it is necessary that it be tested to be sure that it produces valid results. After the original design and construction, our simulator was put through many tests to determine its validity to the real world. These tests, performed by Leonard and Wierwille (1975), involved the taking of data using an instrumented vehicle with a number of subjects over several stretches of highway. With these data, the control computers for the simulator were programmed and adjusted until the simulator produced the same characteristics as the instrumented vehicle. When this work had been completed, it was determined that the simulator produced absolute correspondence in several measures and was therefore valid for use in other vehicle tests.

# LITERATURE REVIEW

While the secondary task method of workload measurement has been used in many areas, it has been used very little in the area of driver workload measurement. Some literature is available involving on-the-road vehicles, but none was found in which a driving simulator was used. Considerable work has been done in the area of vehicle dynamics and their effect on vehicle stability and control. Literature in both of these areas was examined.

## *Workload Theory*

In 1963, Knowles first suggested using a secondary task as a measure of workload. Knowles indicated that the secondary task is used to stress the primary tasks where the two or more primary tasks being studied are of different degrees of difficulty, but are all below some threshold measurement of degradation. In this method the primary task is measured and the more difficult the task, the greater its degradation. Knowles indicated two problems with this use of the secondary task: first, it may be difficult to control the produced stress, and second, severe stress may disrupt the primary task to the point that the operator's behavior is completely changed.

A more important use of the secondary task is to measure the amount of additional work that the subject can do while performing the primary task. Knowles' research indicated that the secondary task information should be short and efficiently coded so that it can be effectively "sandwiched" between the primary task information. Knowles found that the use of discrete stimulus-response units was desirable, and that efficient coding could be obtained by careful attention to stimulus response compatibility, population stereotypes, and thorough learning. For the secondary task to be sensitive it has to be easy, overlearned, and composed of discrete information units.

Brown stated:

> On the model, the man's total channel capacity is drawn at some arbitrary point on the ordinate representing amount of information (in practice of course, it may vary with his state of arousal and other aspects of behaviour). The difference between his capacity and the perceptual load imposed by some imaginary task is his reserve capacity. This clearly depends upon the imposed load, but the important point is that if it exists at all, reserve capacity, and also perceptual load, cannot be measured directly from performance errors on the task in question since, by definition, the man will make no errors.
>
> The diagram also demonstrates the most convenient method of occupying reserve capacity so that perceptual load becomes measureable. The man is required to perform a second task concurrently with the primary task which is being evaluated. On the one-channel hypothesis the load imposed by the dual task can be arranged to exceed his limited capacity so that errors occur (in Rolfe, 1971, p. 136).

Bahrick, Noble, and Fitts (1954) conducted a study to see if performance on a secondary task, practiced simultaneously with a primary task, could be used to measure learning on the primary task that may not be revealed by other conventional measures. Their theory was that motor-sequence learning on the primary task should allow for improved performance on the secondary task.

Their visual-motor (primary) task involved pressing keys as light targets passed a cross hair on the apparatus. The secondary task consisted of the mental subtraction of two numbers read to the subject by the experimenter.

When the visual-motor task was repetitive in nature, there was an improvement in secondary task performance after several trials, even though the score on the primary task showed no significant difference. This supported the hypothesis that learning could be measured in this manner. When the primary task was random, there was no significant change in the secondary performance, indicating that there was less learning under the random pattern for the primary task.

Kelley and Wargo (1967) also investigated the use of a secondary task. To avoid any degradation of the primary task, they operated with what is called a cross-adaptive operator loading task. Under this system the rate of the secondary (operator loading) task is automatically increased or decreased depending on the primary task performance. This method avoids interference but evaluation becomes tedious as the secondary task rate fluctuates in response to changes in the primary task.

In his study of target acquisition and workload, Price (1975) found a single digit random number display to be a satisfactory secondary task. In an attempt to determine the best gimbal order for target acquisition, Price used the single digit random number display at a rate of three presentations per sec for most of the subjects. The study involved side-by-side displays, one showing the random numbers and the other showing aerial films with various gimbal orders. The subjects were required to call out the random numbers while watching for specified targets on the second display. The random number scoring proved to be a successful way of detecting differences in workload that were involved with the various gimbal orders.

Workload theory has been applied to many areas as these articles indicate. These studies all follow the same basic assumptions, as described by Knowles and others, and they demonstrate the ability of a secondary task to measure operator workload under many situations. A more complete review of applications of secondary tasks as a measure of spare mental capacity can be found in Rolfe (1971).

### *Vehicle Handling Characteristics*

Vehicle handling characteristics can be altered considerably to change the way in which a vehicle reacts to driver inputs and to outside conditions. Hoffman and Joubert (1966) ran several experiments involving changes in steering ratio, sight distances, steering torque, straight road *vs* curves, and spare mental capacity. Tests were conducted by measuring the number of pylons touched during the course of the test runs. Initial runs were made at the subject's discretion until he felt that no more improvement could be made. Additional runs were made under the various conditions and the results were measured. Steering ratio changes had some effect, while the effects of other variables were negligible.

Hoffman and Joubert (1968) attempted to determine the just noticeable differences (JND) for vehicle response time, stability factors, and steering ratios. Steering ratios tested ran from 20:1 to 30:1. Vehicle response time was measured as the time difference between rise time of the steering input and the corresponding rise time of the response of the vehicle. The measured response time of the vehicle showed little variation for rates of steering wheel input of 80 to 800 deg/sec and thus appears to be a characteristic time of the vehicle.

The JND for the steering ratio ran from two to less than one depending on the speed of the vehicle. Differences of approximately 1.5 were detectable at 50 mph. In the response time studies, some drivers were able to detect small changes while others were unable to detect any change over the range being tested. Only JNDs were studied; no measurements of workload were made. Therefore, no inference should be drawn concerning the workload involved in handling the test vehicles.

Lincke, Richter, and Schmidt (1973) used both a simulator and automobiles on a test track to study the correlations among the subjective evaluation of the vehicle handling qualities, test measurements, and various handling characteristics. Handling characteristics studied included steering ratios, vehicle response times, and side slip angles. Tests were run in a static simulator with no cabin motion. Later, when a dynamic simulator was completed, the same tests were run and the results agreed with the static simulator. A test track 10 km long with 11 curves was used for the road vehicle testing. The subjects were instructed to drive the course as fast as possible with no mistakes. The tests indicated that vehicles with fast response and small side-slip angles tend to lead to more favorable driver judgements and also to better times on the test track. The test measurements made in the simulators yielded the same results.

Bundorf, Pollock, and Hardin (1963) studied the effects of aerodynamic forces on vehicles. A hydrogen peroxide rocket engine was used to produce up to 200 lbs of side thrust to the vehicles involved. Flow and other forces, including varying tire cornering rates, were measured. The results followed analog predictions very well. It was found that increased overall tire cornering rates can improve both the control and disturbance response characteristics of a passenger vehicle.

Steering ratios have been studied by several investigators. Olson and Thompson (1970) conducted five studies using both fixed and variable steering gear ratios. Vehicles used were identical except for the steering gear ratios. Each subject made several runs with each gear ratio or variable gear ratio. All of the steering systems were power assisted. Ratios of 16-12.2:1, 16-8:1, 16:1, 13.5:1 and 11:1 were tested through parking maneuvers as well as high-speed and low-speed driving tasks. From a subjective standpoint, the 16-12.2:1 variable ratio steering gear system received the best ratings from the subjects. In the high-speed and low-speed tests there was no statistically significant difference in the number of cones displaced.

Shoemaker and Dell'Amico (1966) found that drivers are very adaptable and adjust easily to varying steering ratios. Their study indicates that subjects are capable of handling vehicles with steering ratios as low as 5:1. This is a considerably lower ratio than currently used on any production vehicle. Low-speed and parking maneuvers are difficult with a 5:1 ratio,'but tasks at street or highway speeds can easily be handled. These results indicate that human operators are very adaptable, and give an indication as to why little difference in performance has been detected between different steering gear ratios.

Changes in vehicle handling characteristics and disturbances such as wind gust affect any vehicle that is on the road. The above studies show that even slight changes in vehicle handling characteristics can be detected by measuring the driver's performance and can be subjectively observed by the drivers. The adaptability of human subjects is also apparent from the wide range of vehicle handling characteristics and disturbance levels that can be safely handled by most drivers. This latter characteristic may cause trouble in measuring workload differences caused by changes in the vehicle handling characteristics.

### *Driver Workload*

Brown and Poulton (1961) ran a study attempting to measure the spare "mental capacity" of drivers by using a secondary task. Two groups of subjects were used. The first was a group of average drivers, the second a group of police officers who had all passed an advanced driving course. The primary task involved a 2.2 mile course through city streets, including both heavy and light traffic conditions. The secondary task for the average drivers consisted of listening to pairs of 8-digit numbers and detecting the digit that was different in one number from the other. For the advanced drivers the secondary task was mental addition of three single-digit numbers.

The authors concluded that the secondary task method could be used effectively in field studies to measure the spare "mental capacity" of drivers. The difference in the percentage of errors between the light and heavy traffic conditions appeared to be small; however, the change in mental load also appeared to be small.

McDonald (1973) set out to study driver workload in the freeway environment and to develop a model for predicting the workload on highways during the design phase for the highway. In his study McDonald used a secondary task composed of single-digit random numbers. The first part of McDonald's study involved a tracking task using a steering wheel. A second display was located next to the tracking display. This second display contained the random numbers which the subjects read aloud as they performed the tracking task. This part of the study was used to attempt to verify that the secondary task was sensitive to variations in the workload involved with the tracking task. The secondary task proved to be quite sensitive.

For the second part of this study, McDonald mounted the secondary task display on the hood of a car which was then driven through various highway situations to measure the workload associated with different highway configurations. Runs were made at several speeds and through curves of various radii. The display, which was mounted to the right of the driver's line of sight, slightly obstructed the view on right hand turns. The secondary task was checked for interference with the primary task by monitoring the subjects' lane position with and without the secondary task. There was no significant difference in the lane position measure and therefore no apparent interference from the secondary task.

The secondary task was operated at a rate of two digits/sec for all but two of the subjects. These two subjects were run at three digits/sec. During his testing, McDonald's subjects were found to be from 20 to 40 percent occupied by the driving task, depending upon the curvature and speed involved.

Other methods have been used to attempt to measure driver workload. Senders, Kristofferson, Levison, Dietrich, and Ward (1967) set up experiments to measure what they called attentional demand. Their tests were conducted on a stretch of interstate highway not yet open to the public and on a road course track. The subjects wore a helmet with an opaque visor that could be raised and lowered to control the drivers' vision. When lowered, the visor totally obscured the drivers' vision; when raised, the drivers had a full field of view. Tests were run in which the subject controlled the visor and in which the experimenter controlled the visor. In some tests the viewing time was constant regardless of speed, while in others the speed was constant and the viewing time was varied. All combinations were tested.

The study determined the maximum speeds, maximum obscured vision time, and the minimum viewing times under each of the test conditions. Attentional demand is based on uncertainty caused by road and traffic conditions coupled with the speed of the vehicle. By measuring the viewing time for each condition it was possible to determine the attentional demand or workload for each condition and to compare the workloads across conditions.

Zeitlin and Finkelman (1975) attempted to test two subsidiary task techniques as measures of operator loading. The subsidiary tasks were paired with a primary task of "vehicle steering". The steering actually involved a compensatory tracking task using a line on a cathode-ray tube display, which moved from side to side, being deflected by a quasi-random signal pattern. Steering control was accomplished with a vertically mounted sports car steering wheel linked to a potentiometer. The wheel was self-centering, friction damped, and limited to a rotation range of 270 deg.

The first technique tested was self-generation of random digits. No display of random digits was used; rather, the subjects were to call out "randomly" digits from 0-9. Secondary task performance was evaluated by determining the randomness of the digit sequence under the various tracking conditions. Each subject served as his own control. This technique failed to distinguish among the three load conditions of the primary task.

The second technique tested was that of delayed digit recall. A random digit sequence was presented to the subject via earphones. The subject was to repeat the digit that occurred before the last one presented. This technique consistently differentiated the three load levels of the primary task. Mean number of errors for no load was 3.8, for zero order control the mean was 13.5, and for first order control it was 21.0

Both of these techniques proved to satisfy the fundamental requirements that they be easy to learn and not interfere with the primary task. Random digit generation had proven successful in previous tasks such as card sorting and steady state pursuit tracking; however, as mentioned above, it was unsuccessful in this instance.

Attempts at measuring driver workload in on-the-road vehicles have been successful, but in most cases the equipment or techniques have been less than ideal. Driving conditions have not always been well controlled and displays have sometimes blocked the driver's view of the roadway. None of these studies have used driving simulators, but some of the techniques are similar to those used in this study. This study closely parallels McDonald's study, but with a simulator and a less obtrusive display.

# EXPERIMENTAL METHOD AND DESIGN

## *Simulator*

The data for this experiment were collected using the driving simulator developed at Virginia Polytechnic Institute and State University in the Department of Industrial Engineering and Operations Research. Construction of the simulator and subsequent research have been jointly funded by the General Motors Corporation and the University.

The simulator is composed of four basic units plus auxiliary equipment (see Figure 1). Two of the basic units are analog and hybrid computers (see Figure 2). An EAI-TR-48 is used to simulate the vehicle dynamics and can be programmed to change the vehicle dynamics as desired. The system is closed loop between the computer and the simulator platform. The computer receives signals from the platform that provide data on the steering wheel position, accelerator and brake position, and the current position of the four motion servos. All of this information is constantly updated to the computer and it, in turn, continuously updates the configuration of the platform through control of the electrically activated hydraulic cylinders.

The second computer is an EAI 380 analog/hybrid unit. This unit creates the roadway image which is presented to the driver via a cathode-ray tube (CRT) on the platform (see Figure 3). The EAI 380 controls all of the details of the image,including its speed, curvature, vehicle position within the image, and the vehicle's reaction to wind gusts or driver inputs. The computer receives the output from the TR-48 to accomplish this latter aspect of the image control. The EAI 380 also controls a vibrator on the platform and the sound level at the platform

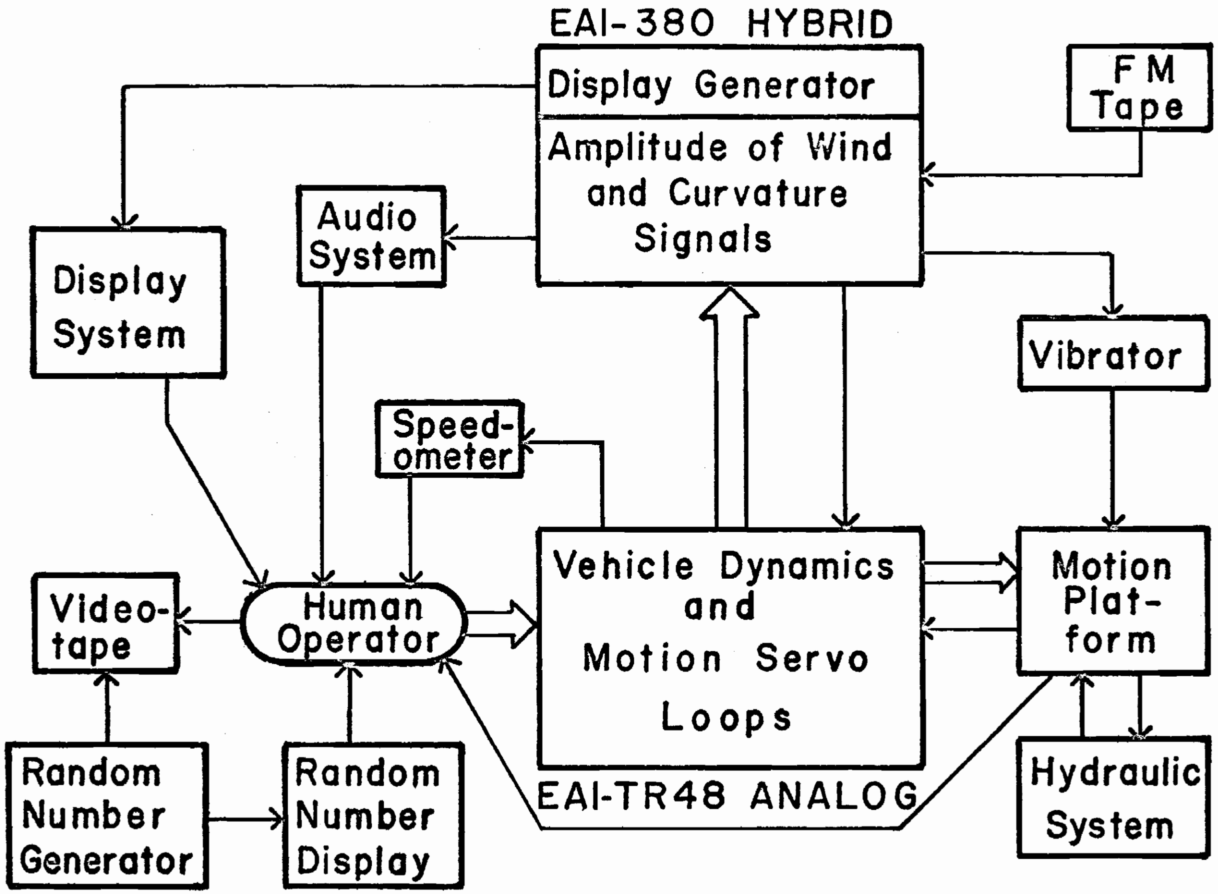

Figure 1. Schematic diagram of simulator.

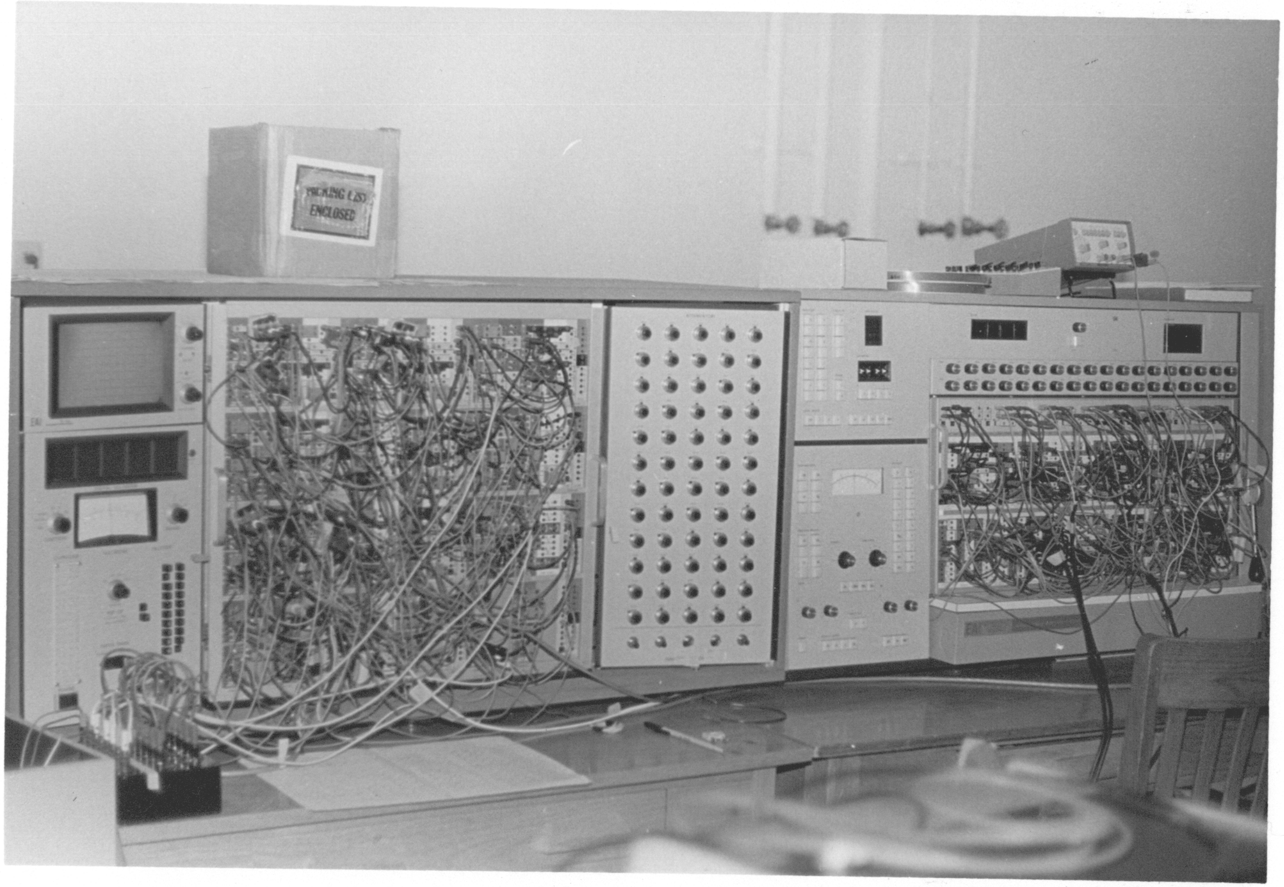

Figure 2. Simulator control computers.

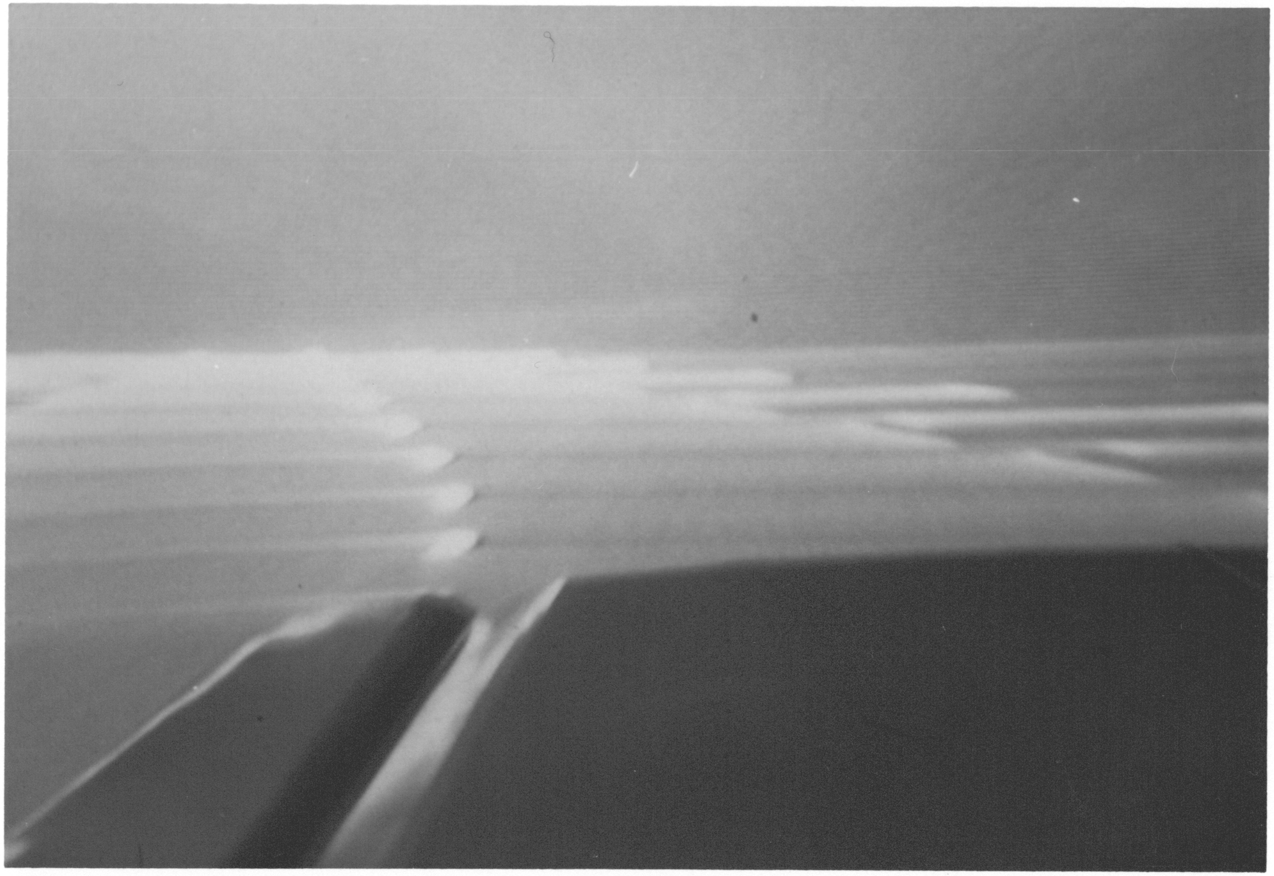

Figure 3. CRT for roadway display of simulator.

so that the level of each corresponds to the vehicle's speed.

The third basic unit in the system is the motion platform (see Figures 4 and 5). It is capable of four degrees of physical motion: roll, yaw, lateral translation, and longitudinal translation. The last of these is short but simulates acceleration and deceleration quite well. The platform is made up of a high fidelity cockpit consisting of a driver's seat, steering wheel, CRT for roadway display, accelerator, brake pedal, and speedometer. The cockpit is mounted on the motion platform, which is powered by four electrically actuated, computer-controlled hydraulic cylinders. (This is an improvement from previous experiments where only three cylinders were used. The lateral translation has been greatly increased and the longitudinal translation added.)

The fourth basic unit is the hydraulic power unit. This unit is also new. It provides nearly double the hydraulic pressure (1500 PSI) for much faster and more consistent responses than were previously possible. The system comes from a numerically controlled milling machine and contains a pump, an accumulator, and a cooling system for the oil. The accumulator in the system allows for large oil flow with only a slight drop in the oil pressure. During operation the pressure seldom drops below 1350 PSI.

The entire system is a complex yet flexible unit. Its programming can be changed to produce a wide range of vehicles and a wide range of road conditions. It is also capable of receiving various inputs to control wind gusts or other disturbances. These inputs can be constant or of a random nature. Further descriptions of the simulator (before addition of the fourth servo) can be found in Wierwille (1973), McLane and Wierwille (1975), and Wierwille and Fung (1975).

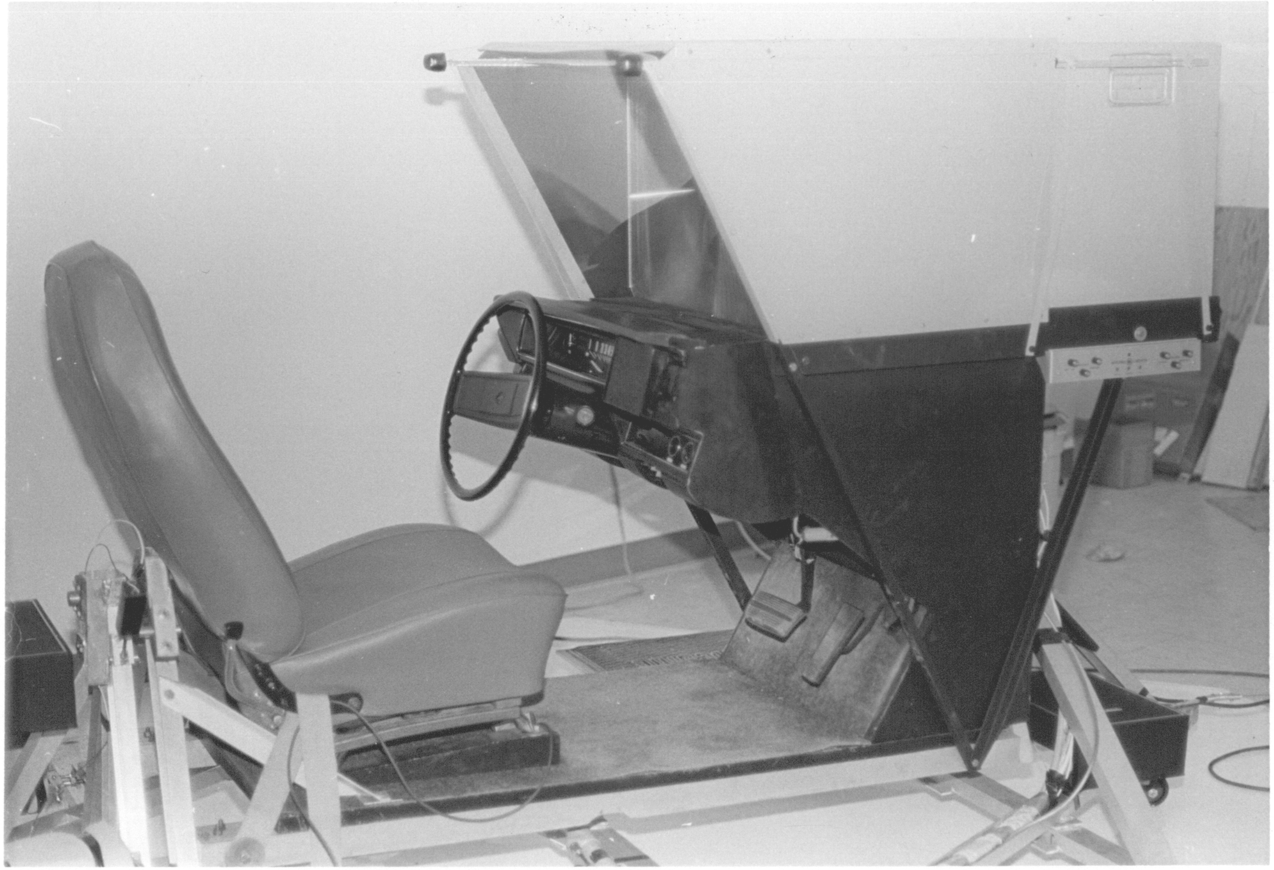

Figure 4. Driving simulator motion platform.

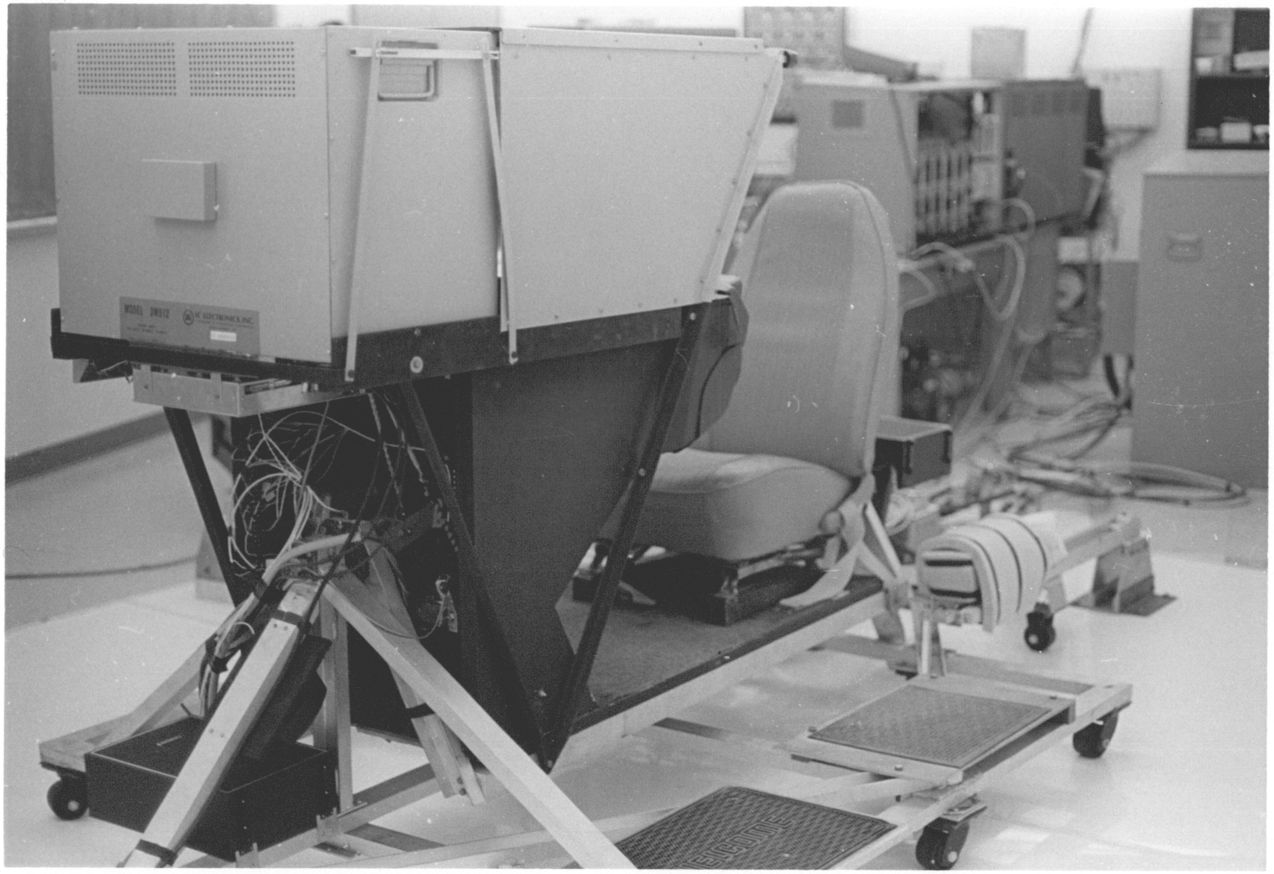

Figure 5. Driving simulator motion platform.

### *Auxiliary Equipment*

To control the wind gusts and curvature pattern of the roadway and to provide for repeatability from subject to subject, an FM tape was recorded. The tape also contained a time line so that the length and spacing of the experiment segments would be the same for all subjects. These three functions were recorded and played back on a Sanborn/Ampex 2000 FM tape recorder. The FM inputs were fed to the EAI 380 computer which generated the CRT display and controlled the wind gust inputs to the display and the motion platform. The EAI 380 made amplitude changes only in these signals. These variations created the variations in the subject workload which produced the different experimental conditions.

Part of the experimental procedure involved the monitoring of the subject's lane position, his speed, and other vehicle parameters for possible later evaluation. A Sanborn 350, 8-channel chart recorder was used to record the above items by receiving inputs from the EAI TR-48 computer.

### *Secondary Task Equipment*

The secondary task or operator loading system encompassed both the production of the task stimulus for the driver/subject and the recording of the subject's responses. To produce the task, a random number generator was built (see Figure 6). The device was capable of producing a single digit random number from 0 through 9. The digits were created at a rate continuously variable from one every two sec to four per sec. This range covered the capabilities of all of the subjects. The digit display was a 1/2 in. light emitting diode, which was placed on the hood of the simulator. The display was approximately 8 deg to the right of

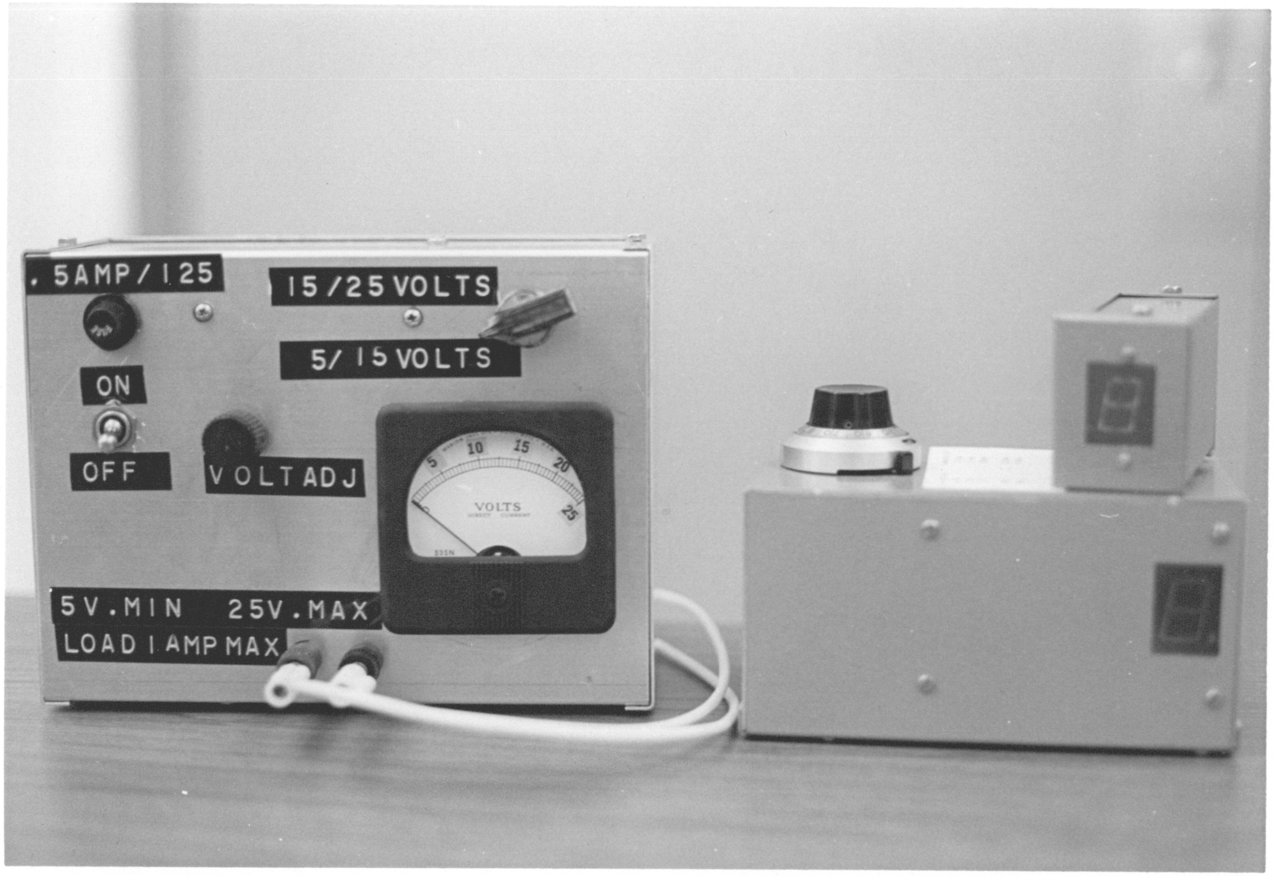

Figure 6. Power supply, random number generator, and subject display for simulator.

the driver's line of sight. The display subtended an angle of approximately 0.8 deg. This angle is at least twice as large as necessary and yet is small enough to prevent blockage of the roadway view. The luminance of the display caused little glare. The subject had to look at the display in order to read it; it could not be read using peripheral vision (see Figure 7).

To record the display and the subjects' responses, a JFD 700 video tape recorder was used. A second digital display was placed in front of a Dage RGS 50 TV camera, and its output, along with the voice responses of the subject, was recorded. This procedure permitted off-line scoring and rechecking where necessary.

### *Experimental Design*

Before the workload measure could be utilized to evaluate variations in workload, it was necessary to show that it was a sensitive measure. To do this, a set of four paired combinations (conditions A, B, C, D) of wind gusts and lane curvatures was used. These combinations were fed to the EAI 380 via the FM recording. The combinations were constant on the FM tape and their amplitude was adjusted by the EAI 380. These two input variables were adjusted simultaneously by the same factor. Each successive combination had an amplitude that was approximately twice that of the preceding combination. These relative levels (1, 2, 4, 8) were used because exact values depend on the aerodynamic properties, weight, and other vehicle factors. Exact values would have required testing on the road or in a wind tunnel and would be applicable only to the one vehicle. During these sessions, all other parameters were held constant. The

Figure 7. Simulator display with random number display on hood, looking over subject's shoulder.

range of these levels left no doubt as to the variation in workload. The lowest level of wind and curvature was so slight as to cause no difficulty for even a novice subject, while the highest level was very difficult to handle. The relative differences were used to test for sensitivity of the secondary task to driving workload changes.

The second area studied was the measurement of workload changes caused by changes in vehicle handling parameters. Two parameters were varied. The first parameter to be changed was the steering ratio. Four steering ratios (conditions C, E, F, G) were used including the one (condition C, 0.125) used for the sensitivity section of the study. The ratios used were 0.100, 0.125, 0.170, and 0.250 deg/sec/deg (degrees per second of yaw rate per degree of steering wheel rotation). The second parameter changed was vehicle response time (conditions, C, H, I, J). Vehicle response time is defined as the time it takes for the vehicle yaw rate to reach 90% of the final value caused by a step input to the steering wheel. There were four levels, 0.76, 0.44, 0.28, and 0.19 sec. The third of these (0.28) was used for the sensitivity section (condition C) of the study. The handling parameters used during the sensitivity section of the study were set to correspond to an average mid-size vehicle, approximately those of a Chevrolet Nova. Of the other three levels of each parameter, one level should have made it easier to handle the vehicle and two levels should have made it harder to handle the vehicle. The handling parameters were adjusted independently; one remained at the Nova setting while the other was adjusted. During all of the testing of these parameters, the wind and curvature patterns were held constant at the next to highest level (condition C).

The two areas of the study, sensitivity and vehicle handling parameters, utilized a total of 10 conditions (A through J). For analysis purposes, these were grouped in three single factor experiments, each containing four conditions, condition C being common to all three experiments. Subjects were assigned randomly and operated under only one of the 10 conditions. Only one variable was changed at a time and therefore there are no analyzable interactions among the variables.

### *Experimental Safeguards*

To avoid any bias due to potential drift in the simulator electronics, all of the data for all 10 conditions were taken over as short a period as possible. The experimental conditions were run serially. This precaution was taken to provide for equal sample size if there had been any reason for the experiment to be shortened. Care was also taken to run subjects from each experimental condition at various times of the day to prevent any time-of-day effects. Table 1 shows the experimental conditions and the serial order (A through J) used.

It is not reasonable to assume that the secondary task had no effect on the primary task. To reduce any possible interference therefore, careful consideration was given to the choice of the secondary task. However, there remains the possibility that a subject did not give full attention to the primary task as instructed.

To be sure that each subject met the criteria of lane position and speed, these were continuously recorded during the data run. Allowable limits for these measures were established during preliminary testing. It was determined that the subject could, even under the heaviest work-

Table 1. Experimental Condition Combinations

| Condition | Wind Gust and Curvature Level | Steering Gain Level | Response Time |
|---|---|---|---|
| A | 1 | 0.125 | 0.28 |
| B | 2 | 0.125 | 0.28 |
| C | 4 | 0.125 | 0.28 |
| D | 8 | 0.125 | 0.28 |
| E | 4 | 0.100 | 0.28 |
| F | 4 | 0.170 | 0.28 |
| G | 4 | 0.250 | 0.28 |
| H | 4 | 0.125 | 0.76 |
| I | 4 | 0.125 | 0.44 |
| J | 4 | 0.125 | 0.19 |

| Wind Gust and Curvature Levels | |
|---|---|
| 1 | Very Low |
| 2 | Low |
| 4 | Medium |
| 8 | High |

load condition, maintain lateral position limits that would put either wheel outside of the driving lane by no more than 3 ft for an accumulated time of not more than 15 sec out of the 90-sec data run. Likewise, it was determined that the subjects could maintain their assigned speed of 55 mph ± 10 mph and not be outside these limits for an accumulated time of more than 15 sec out of the 90-sec data run.

If either of the above criteria were violated during test runs, it would mean that the subject had attended to the secondary task and was not giving proper attention to the driving or primary task. If this happened, the data for the subject were eliminated from the set for that condition. (It was necessary to discard the data from 2 of the 84 subjects that participated in the study.)

The lane position data were further analyzed as a measure of driver performance. There were three objectives in this analysis. The first objective was to attempt to measure the intrusiveness of the secondary task. The second was to measure any degradation in primary task performance across levels of the experimental conditions. A degradation of this type could indicate that subjects attended inappropriately to the secondary task. This would prevent the secondary task from measuring workload differences among the conditions. The third objective was to verify the workload differences in the sensitivity segment (conditions A, B, C, D).

Each subject's lane position was sampled at 1-sec intervals during three segments while driving and reading random numbers and during two segments while driving only. Each of the five segments was approximately 25 sec long. The subjects had been instructed to drive in the center of the right hand lane. To allow for individual differences in perceiving the center of the lane, the mean lane position was calculated for each subject. The mean deviation from this "lane center" was calculated for each subject. One mean was calculated for the three segments which included driving and reading random numbers and a separate mean was calculated for the two segments which included driving only.

### *Subjects*

The driver/subjects for the study were drawn from the general VPI & SU student body and were paid. The only requirements were that the subjects have a valid driver's license and had been driving for at least two years. Vision was checked only to the extent that the subject could see and read the random digit display of the secondary task. The subjects ages ranged from 18 to 24. There were 47 males and 35 females. Eight conditions had eight subjects each and two conditions had nine subjects each.

### *Experimental Procedure*

Upon arrival, the subject's name, age, sex, and years of driving experience were recorded. The subject was then assigned a number corresponding to the next test condition. After this information had been listed, the subject was given a set of instructions designed to provide information on the task to be performed during the experiment and also to describe the experiment in general. A copy of these instructions is in Appendix A. While the subject was reading instructions, the two computers were adjusted and all other preparatory work was completed. After reading the instructions, the subject was allowed to ask questions.

To begin the experiment the subject was taken into the simulator room and seated in the simulator, the seat belt was fastened, and the microphone for recording voice responses was placed around the subject's neck. Next the subject was shown the emergency button that was to be pushed if for some reason the subject felt that the run could not be completed. (No one used the button.)

The first segment of the experimental session was devoted to practice on the secondary task and its adjustment (increments of 0.5 digits/sec) to a presentation rate just above the subject's capability. Once this rate was set, it remained constant. This was done with the simulator display activated, but not moving. The hydraulics and other systems were in the standby mode so that the subject could become accustomed to the noise level of the hydraulic system. After the subject had practiced at several presentation rates, the rate for the subject was set by observing the performance at the upper end of the subject's capability. The rate was then set as defined above. At this point a 40-sec trial was videotaped for later scoring.

The second segment of the session was devoted to practice using both the simulator and the secondary task. This practice run had the same wind and curvature parameters as the later data run, but the run was only similar to the data run - not identical. The subject was instructed to keep the vehicle speed as close to 55 mph as possible, but was to move back and forth across both lanes in order to get a feel for the simulator and its responses to steering inputs as well as the reaction to wind and curvature during such maneuvers. The practice session was 4.75 min long. During this period, the subject was asked to read to numbers from the secondary task at three different times for periods of 30 sec each. This was done while the subject drove at 55 mph in the right lane as required later during the data run.

At the end of the practice session a break was taken. During this 2.75 min break, the subject was allowed to rest under subdued light conditions. Questions were answered for the subject during the period, the instructions pertaining to speed and lane position were repeated, and the importance of the primary task was again emphasized. The subject's reactions to the simulator and the task were discussed if the subject made any comments concerning the simulator or the driving task.

Following the break, the actual data run was made. This segment of the session lasted 4 min, 35 sec. During this time the subject was asked to drive at 55 mph and to remain in the center of the right lane for the entire segment. At three equally spaced times during the data segment, the subject was asked to read numbers from the random number display. Each of these number reading sessions was 40 sec long and the numbers as well as the subject's responses were recorded on videotape for later scoring. Also on the videotape was the image of a voltmeter. The meter was deflected by a signal from the FM tape. These signals indicated the beginning and end of each number reading period. These data, when compared to the 100% attention score, produced the workload measure.

The last segment of the experimental session was used to check again the subject's number reading speed while reading only. The subject was given a short break after the data segment was completed and was then asked to read the random numbers for a period of 40 sec.

These responses and numbers were again videotaped for later scoring. When averaged with the first segment, these data provided the 100% attention score for the subject.

When all segments were complete, the subject was paid for his/her participation. This completed one experimental session. Each session took approximately 25 min. The time line for the experimental session appears in Appendix B.

### *Data Processing*

All of the secondary task data was on videotape from the 84 subjects that drove the simulator. Also recorded on the Sanborn 350 chart recorder were the speed and lane position for each subject during the data segment. The first step in the data processing was to evaluate each of the subjects against the previously listed speed and lane position criteria. In making this evaluation, it was found that the subjects had done very well and that only 2 of the 84 had violated the criteria. This left 82 subjects, 8 subjects in each of 8 experimental conditions and 9 in the other two.

To analyze the subjects' number reading scores, it had been thought that the videotape could be played back at normal speed and scored. This proved extremely difficult because of the presentation rates used and because there was always a slight delay between the presentation of the number and the subject's response. Because it was not possible to slow the playback speed of the JFD 700 video tape recorder, the tapes were re-recorded onto 1-in. videotape on an IVC 860C video tape recorder. At the slower speed the sound became untelligible. Thus, it became necessary to list all of the numbers presented to each subject. The numbers were listed from the slowed videotape, following which the subjects' responses were played back at normal speed and each subject was scored. After the scoring was complete, the workload for each subject's experimental condition was calculated based on Knowles' formula:

$$W = 100 - (W_1 + W_t) \qquad (1)$$

where

$W$ = primary task load

$W_1$ = secondary task load

$W_t$ = eye transition time load

$W_1 = \frac{N}{Nmax} \times 100$

$N$ = percent correct responses during data segment, and

$Nmax$ = percent correct responses during 100% attention segment.

$W_t$ has been specified as zero in this experiment. With the small angle between the simulator display and the random number display, the eye transition time is on the order of 0.05 sec (Taylor, 1975). With this very short time per transition it was thought reasonable to ignore $W_t$. The comparisons of workload across various conditions would not have been affected since $W_t$ would have been very small and reasonably constant.

The workloads were calculated for each of the 82 subjects and they appear in Appendix C. The means and variances for each condition also appear in Appendix C. The range of workload scores is very wide (-5.41 to 67.43) and the range of the variances is also wide (48.19 to 464.46). The negative workload scores, while unrealistic, are probably due to experimental error. The wide range of the variances is caused by a wide range of scores within individual conditions.

The lane position data was processed electronically. The chart strip from the Sanborn 350 chart recorder was scanned for each subject using a Science Accessories Corporation GRAF/PEN. The data were fed on line to a Digital Equipment Corporation PDP 11/10 computer through an LPS-11 front end. The data were stored on tape and later analyzed by the PDP 11/10. The data appear in Appendix D. The units used are intrinsic to the GRAF/PEN. Each unit equals approximately 0.223 ft.

# RESULTS

As indicated earlier, there were three single factor experiments to be analyzed (see Table 2). Analyses of variance produced nonsignificant ($p > .05$) results for all three comparisons. Testing of the variances using Hartley's *F*-max test indicated significant differences ($p < .01$) among the four variances in each of the three groups of data. The variances were obviously heterogeneous.

In an attempt to reduce the heterogeneity of variance, a logarithmic transform was applied to the workload data. Analyses of variance on the transformed data showed significant differences among the sensitivity groups (A, B, C, D) only. The variances were still heterogeneous (Hartley's *F*-max, $p < .01$).

Both the original and the transformed data violate the assumptions of parametric statistics. This does not make parametric methods unuseable (Norton in Lindquist, 1953), but the potential for type II error is increased. The violation of the assumptions also justify the use of nonparametric statistics.

The Kruskal-Wallis one-way analysis of variance and the Kruskal-Wallis multiple comparison tests were used. Kruskal-Wallis one-way analyses of variance were run on all three groups of workload data and the multiple comparison test was run where statistical significance was shown by the analysis of variance.

The lane position data were analyzed using parametric statistics only. These data met the parametric assumptions. The data were grouped into three four-by-two analyses. Driving conditions were grouped as

Table 2. Data Grouping for Analysis

| | Workload Sensitivity | Steering Gain Workload | Response Time Workload |
|---|---|---|---|
| Conditions | A,B,C,D | C,E,F,G | C,H,I,J |

before (see Table 2). The second variable was the reading or not reading of random numbers while driving. Newman-Keuls tests were also performed where appropriate.

### *Workload*

The Kruskal-Wallis one-way analysis of variance found significant differences ($p < .05$) among test conditions for the sensitivity segment (wind gust and curvature) data. The tests for variations in workload caused by changes in the steering gain or response time of the vehicle produced no significant results. All of these results appear in Table 3. The parametric results were not in disagreement with these nonparametric results.

The Kruskal-Wallis multiple comparison was used only on the sensitivity segment data. These comparisons found a significant difference ($p < .025$) for only the A *vs* D conditions. These are the extremes and a difference was expected. Condition D provided a higher workload than condition A.

### *Driver Performance*

Analyses of variance on the driver performance (lane position) data, (see Tables 4, 5, and 6) found significant differences among test conditions for only the sensitivity segment ($p < .001$). Newman-Keuls tests on conditions A, B, C, and D indicated significant differences for the three comparisons that included condition D, (A-D, B-D, C-D) at $p < .05$. None of the other comparisons produced significant differences. Condition D produced a higher workload level than conditions A, B, or C, but

Table 3. Kruskal-Wallis One-Way Analysis of Variance Results

| Conditions: | A | B | C | D |
|---|---|---|---|---|
| Rank Totals: | 73.5 | 131 | 133.5 | 190 |

H value for group (9.609) significant at $p < .05$

| Conditions: | C | E | F | G |
|---|---|---|---|---|
| Rank Totals: | 149 | 105 | 133 | 174 |

H value for group (2.094) not significant ($p > .05$)

| Conditions: | C | H | I | J |
|---|---|---|---|---|
| Rank Totals: | 114.5 | 176 | 143 | 127.5 |

H value for group (1.455) not significant ($p > .05$)

Table 4. Analysis of Variance Summary Table for Driver Lane Position during Sensitivity Segment - Conditions A, B, C, D

| Source | df | MS | F | *p* |
|---|---|---|---|---|
| Wind Gust and Curvature Load (L) | 3 | 26.015 | 16.310 | < .001 |
| Subjects (S/L) | 27 | 1.595 | | |
| Secondary Task (ST) | 1 | 4.513 | 11.316 | < .01 |
| L X ST | 3 | 1.433 | 3.91 | < .025 |
| ST x S/L | 27 | 0.367 | | |
| Total | 61 | | | |

Table 5. Analysis of Variance Summary Table for Driver Lane Position with Variations in Steering Gain - Conditions C, E, F, G

| Source | df | MS | F | *p* |
|---|---|---|---|---|
| Steering Gain (SG) | 3 | 1.886 | 1.186 | > .25 |
| Subjects (S/SG) | 28 | 1.590 | | |
| Secondary Task (ST) | 1 | 11.367 | 10.972 | < .01 |
| SG x ST | 3 | 1.173 | 1.133 | > .25 |
| ST x S/SG | 28 | 1.036 | | |
| Total | 63 | | | |

Table 6. Analysis of Variance Summary Table for Driver Lane Position with Variations in Vehicle Response Time - Conditions C, H, I, J

| Source | df | MS | F | *p* |
|---|---|---|---|---|
| Vehicle Response Time (RT) | 3 | 3.673 | 2.717 | > .10 |
| Subjects (S/RT) | 28 | 1.352 | | |
| Secondary Task (ST) | 1 | 2.144 | 5.204 | < .05 |
| RT x ST | 3 | 0.154 | < 1 | |
| ST x S/RT | 28 | 0.412 | | |
| Total | 63 | | | |

conditions A, B, and C were not statistically different from one another. See Figure 8.

Significant differences were found in driver lane position when the reading and nonreading trials were compared, this was true in all three groups of data (A, B, C, D: $p < .01$; C, E, F, G: $p < .01$; C, H, I, J: $p < .05$). The nonreading trials showed smaller deviations in lane position under all test conditions. The *L* x *ST* interaction was significant ($p < .025$) for the sensitivity segment data. To analyze the interaction, Newman-Keuls tests were run on the driver performance scores across conditions A, B, C, and D. A significant difference ($p < .05$) between the reading and nonreading driver performance scores was found for only condition D. This interaction is shown in Figure 8.

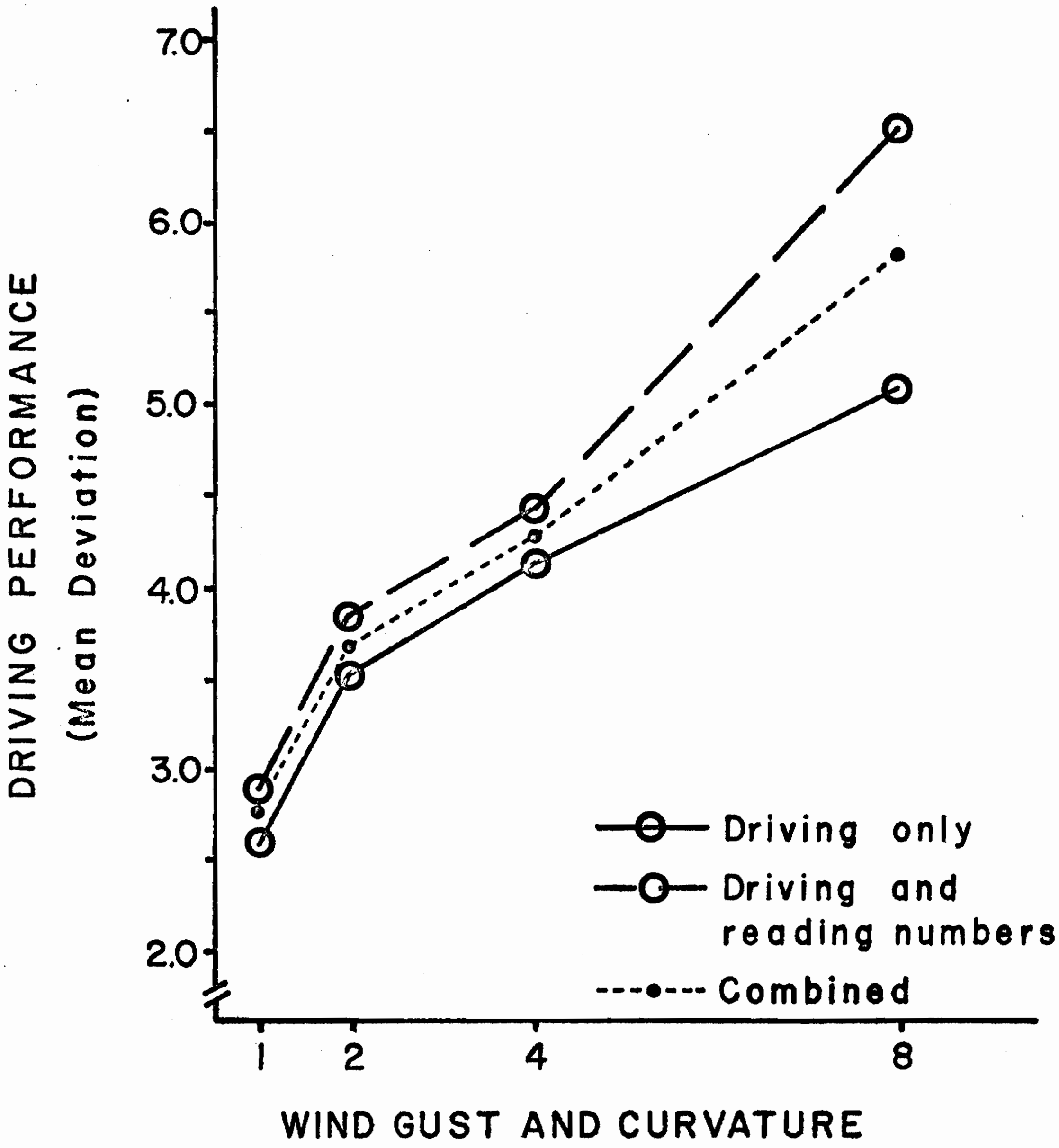

Figure 8. Driving performance for subjects in conditions A, B, C, and D.

## DISCUSSION AND CONCLUSIONS

Examining the results, the only strong conclusion that can be drawn is in the test for sensitivity of the workload measure. The significant difference at $p < .05$ in the Kruskal-Wallis one-way analysis of variance and the significant difference at $p < .025$ for the extreme pair of conditions under the Kruskal-Wallis multiple comparison test lead to the confident conclusion that the measure is sensitive, at least to large workload differences.

The lack of significant differences between the closer pairs of conditions in the sensitivity segment of the experiment leads to the conclusion that the measure, as employed here, was either erratic or incapable of detecting fine differences in workload, if any existed.

Measurement of the subjects' driving performance suggested that they drove more precisely when they were not reading random numbers. The significant difference produced by the interaction between the wind gust/curvature levels and the secondary task level (reading or not reading numbers) indicates varying effects of the secondary task at different levels of primary task. The differences in performance scores indicate that the secondary task may be intrusive. The interaction and the Newman-Keuls results indicate that the secondary task is more intrusive at the higher workload level.

Intrusiveness of the secondary task must be minimized to avoid biasing the workload results. The driving performance differences indicated the possibility of intrusiveness. The extent of the intrusiveness might be observed by the fact that the largest increase in mean deviation while reading random numbers was 4.08 in. None of the subjects indicated difficulty performing the tasks simultaneously. This subjective evaluation coupled with the small increase in mean deviation imply that the intrusiveness may not be severe enough to negate its use.

The driving performance was also analyzed as a means of detecting workload differences across driving conditions. The significant differences found among the sensitivity segment conditions affirm the assumption that the conditions provided variations in the level of difficulty of the driving task. The lack of significant differences in driving performance across the other two groups of data cannot be interpreted to mean that there were no differences in workload among the conditions. These results do indicate that the subjects followed the instructions and drove consistently; if there was a significant difference in workload, performance on the secondary task should have changed. This leads to the same conclusion as the workload data. Either the measure was insensitive to small differences in workload or there were no differences in these two groups of data.

One of the purposes of the study was to develop a measure and equipment that could be used in both simulators and on-the-road vehicles. The random number display proved itself very well, but the secondary task produced signs of intrusiveness. The equipment has been developed, but the procedure needs to be perfected.

There are other conclusions to be drawn concerning the overall experiment. Looking at the raw data it was observed that a number of subjects produced perfect scores on the second half of their 100%

attention test. It was also observed that a number of these subjects performed better on the secondary task while driving than they did on the first half of their 100% attention test. This caused some very low workload scores and even some negative scores. The first conclusion to be drawn here is that these subjects, and possibly others, were not given enough practice on the secondary task before their final presentation rate was chosen and the first 100% attention test was run. If the additional practice had been given it is probable that this problem would have been avoided.

A second problem that was discovered too late to be corrected was the large variance that appeared in many of the workload categories and the large differences in variance among categories. These differences among categories might have been reduced by screening the subjects. If screening were used, only the better drivers who performed well on the secondary task would be chosen as subjects for the workload study. Specific criteria would have to be developed. It is also possible that the correction of the first problem discussed above would have reduced this problem by bringing the low and negative workload scores up to the level of the other scores.

# RECOMMENDATIONS

The first correction that must be made, as mentioned in the conclusions, is to allow the subject more practice on the secondary task before setting the final rate. One way to accomplish this is to wait until the break between the practice segment and the data segment to set the final presentation rate for each subject. This would also mean that the first half of the 100% attention score would be taken during the break instead of at the very beginning of the session. The purpose of a split 100% attention score is to allow for any learning that may take place. In the present experiment there was too much time and practice between the first half of the 100% attention score and the data segment of the experiment. This practice must come beforehand if the split 100% attention score is going to account only for learning that may take place during the data segment.

After looking at the raw data it is also possible to state that many of the subjects were not taxed enough by the rate chosen for them on the secondary task. There was apparently too much concern by the experimenter over the possibility of overloading the subject and not enough concern about forcing the subject to handle as high a rate as possible. This problem might be solved by allowing more practice, but care must still be taken to tax the subjects.

Midway through the study, an effort was made to analyze the data to determine the validity of the procedures. This check was not completed because of the difficulties mentioned earlier in scoring the subjects. This check would have detected the problems with the secondary task. This would have allowed for corrections and changes rather than continuing the experiment.

Scoring of the subjects was very laborious in this study. There are at least two ways that this problem can be corrected. The random numbers that were used in this study were exactly that; there was no predictable or repeated list of numbers. Having a known list would make the scoring much easier. A second solution would be to disregard the numbers themselves and simply count the number of responses made by the subject during the specified periods. In examining the raw data, it was clear that a subject tended to say nothing if he missed a number rather than say an incorrect number. It was found over the 82 subjects that less than 1% of the responses were incorrect and that they occurred equally during the 100% attention segments and the data segments. This would mean that scoring by simply counting responses should be as accurate as any other method and much easier.

# REFERENCES

Bahrick, H. P., Noble, M., and Fitts, P. M. Extra-task performance as a measure of learning a primary task. Journal of Experimental Psychology, 1954, 48, 298-302.

Barrett, G. V. and Thornton, C. L. Relationship between perceptual style and simulator sickness. Journal of Applied Psychology, 1968, 52, 304-308.

Brown, I. D. and Poulton, E. C. Measuring the spare "mental capacity" of car drivers by a subsidiary task. Ergonomics, 1961, 4, 35-40.

Bundorf, R. T., Pollack, D. E., and Hardin, M. C. Vehicle handling response to aerodynamic inputs. Paper 716B, SAE International Summer meeting, June 1963.

DeGreene, K. B. Systems psychology. McGraw-Hill, Inc., 1970, Chapter 7.

Hoffman, E. R. and Joubert, P. N. The effect of changes in some vehicle handling variables on driver performance. Human Factors, 1966, 8, 245-263.

Hoffman, E. R. and Joubert, P. N. Just noticeable differences in some vehicle handling variables. Human Factors, 1968, 10, 263-272.

Kelley, C. R. and Wargo, M. J. Cross-adaptive operator loading tasks. Human Factors, 1967, 9, 395-404.

Knowles, W. B. Operator loading tasks. Human Factors, 1963, 5, 155-161.

Leonard, J. J. and Wierwille, W. W. Human performance validation of simulators: theory and experimental verfication. Proceedings, Human Factors Society Annual Meeting, October, 1975, 446-456.

Lincke, W., Richter, B., and Schmidt, R. Simulation and measurement of driver vehicle handling performance. SAE Paper 730489, May 1973.

Lindquist, E. F. Design and analysis of experiments in psychology and education. Boston: Houghton Mifflin, 1953.

McDonald, L. B. A model for predicting driver workload in the freeway environment: a feasibility study. Texas A & M University, Ph.D. dissertation, 1973.

McLane, R. C. and Wierwille, W. W. The influence of motion and audio cues on driver performance in a simulator. Human Factors, 1975, 17, 488-501.

Olson, P. L. and Thompson, R. R. The effect of variable-ratio steering gears on driver preference and performance. Human Factors, 1970, 12, 553-558.

Price, D. L. The effects of certain gimbal orders on target acquisition and workload. Human Factors, 1975, 17, 571-576.

Rolfe, J. M. The secondary task as a measure of mental load. In Singleton, W. T. (Ed.) Measurement of man at work. New York: Van Nostrand-Reinhold, 1971, 135-148.

Senders, J. W., Kristofferson, A. B., Levision, W. H., Dietrich, C. W., and Ward, J. L. The attentional demand of automobile driving. Highway Research Record, 1967, 195, 15-32.

Shoemaker, N. and Dell'Amico, F. A pilot experiment on driver task performance with fixed and variable steering ratio. Cornell Aeronautical Laboratory, CAL No. VK-2185-R, September, 1966.

Taylor, D. F. Computerized analysis of eye movements during a static, competition search. Virginia Polytechnic Institute and State University, M.S. Thesis, 1975.

Wierwille, W. W. A part-task driving simulator for teaching and research. Computers in Education Transactions of ASEE, 1973, 5, 193-203.

Zeitlin, L. R. and Finkelman, J. M. Subsidiary task techniques of digit generation and digit recall as direct measures of operator loading. Human Factors, 1975, 17, 218-220.

# APPENDIX A

# SUBJECT INSTRUCTIONS

## SUBJECT INSTRUCTIONS
## Driver Workload Study

The experiment you are about to participate in is designed to study variations in driver workload. Different conditions will be presented to different subjects and the ease or difficulty of handling the conditions will be measured. To do this, a measure of "spare time" will be made. You will see a single digit random number along with the roadway view. You will be asked to drive the simulator and read the numbers aloud at the same time. The simulator is computer controlled and hydraulically powered. You are to drive the simulator as if driving a normal car. When you enter the simulator room, you will be shown the simulator's operation as well as its safety provisions.

### PART I

You will read the random numbers without driving the simulator and the presentation rate will be adjusted to your capabilities. The rate will force you to make some errors. After the adjustments have been made, a thirty second trial will be conducted to determine your performance.

### PART II

This will be a practice run. You will "drive" the simulator over straight and curved roadway and there will be some crosswinds at various times. When the simulator is started, you are to bring it up to 55 mph using the accelerator and the speedometer. You may change lanes to get a feel for the steering, but <u>do not</u> go off the roadway on either side. You will be asked at three different times to read the random numbers <u>while keeping the car centered in the right hand lane</u>. There will be a short break after the practice run.

### PART III

This will be your data run. You are to bring the car up to 55 mph and try to keep the car in the right hand lane at all times. At three times you will be asked to read the random numbers. This is to be done in your <u>"spare" time only; driving the vehicle is your primary task</u>. At the end of your data run, another thirty second trial will be conducted using only the random number portion of the task. This will end your portion of the experiment and you will be paid as you leave.

<u>REMEMBER</u>

1) Keep the vehicle at 55 mph.
2) Keep the vehicle centered in the right hand lane unless instructed to do otherwise.
3) Driving is the primary task; the reading of the numbers is to be done only when you have "spare" time.

# APPENDIX B

# EXPERIMENT TIME LINE

## TIME LINE
### Driver Workload Study

| Time | Event |
|---|---|
| Prior to run | Set TR-48 Pots and 380 Pots |
| | Seat Subject and Familiarize |
| | Lights out |
| | Start Random Number Generator |
| | Adjust Rate as Subject Reads |
| | Record Final Rate |
| | Start Video Recorder |
| | Put Subject Number on Videotape |
| | Time 40 Second Trial - Numbers Only |
| | Check TR-48 in Reset, 380 in Operate |
| | Start Flow |
| -:10 | Start FM Tape and Sound |
| :00 | First Meter Deflections Observed |
| :15 | Warn Subject and TR-48 to Operate |
| 1:05 | Noise Begins |
| 1:35 | Curvature Begins |
| 1:40 | Start Watch |
| 2:10 | Watch at :30- Have Subject Read #s for :30 |
| 3:10 | Watch at 1:30- Have Subject Read #s for :30 |
| 4:10 | Watch at 2:30- Have Subject Read #s for :30 |
| 4:45 | Practice Run Ends |
| | TR-48 to Reset Lights on (Lamp) |
| | Flow Stopped and Sound Off |
| 4:50 | Rest Period Begins - Go Over Instructions For Data Run - Answer Questions - Emphasize Priority of Tasks, Remaining in Right Lane and Speed |
| 7:35 | End of Rest Period |
| | Lights Off |
| | Flow Started - Sound On |
| | Subject Warned - TR-48 to Operate |
| 8:05 | Noise and Curvature Begin |
| 8:35 | Videotape on - Chart Recorder on - Data Run Begins |
| 9:00 | Start Subject Reading Random Numbers |
| 9:40 | Stop Subject |
| 10:10 | Start Subject |
| 10:50 | Stop Subject |
| 11:20 | Start Subject |
| 12:00 | Stop Subject |
| 12:10 | Data Run Ends - TR-48 to Reset |
| | Flow Stopped and Sound Off |
| | Video and Chart Recorders Off |
| | FM Tape Off |
| After run | Subject Reminded of Random Number Trial |

Videotape On
Subject Trial Recorded - :40
Videotape Off
Room Lights On
Subject Removed from Simulator
FM Tape Rewound
Sound Tape Checked - Rewound if Necessary

Sequence Repeated

# APPENDIX C

# WORKLOAD SCORES

## WORKLOAD SCORES

### Percent Occupied by Driving Task

|  | Driving Condition |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | A | B | C | D | E | F | G | H | I | J |
|  | 6.09 | 16.67 | 20.87 | 40.90 | 4.83 | 28.93 | -5.41 | 33.94 | 39.66 | 21.45 |
|  | -2.75 | 67.43 | 23.59 | 55.09 | 11.30 | 22.02 | 43.69 | 8.11 | 37.39 | 43.76 |
|  | 13.96 | 23.56 | 20.80 | 42.25 | 2.56 | 2.92 | 42.86 | 32.35 | 2.60 | 2.30 |
|  | 16.77 | 34.50 | 12.78 | 30.08 | 5.19 | 21.63 | 22.98 | 31.56 | 12.54 | 2.06 |
|  | 2.75 | -2.03 | 14.69 | 6.43 | 15.67 | 13.87 | 38.31 | 2.98 | 36.45 | 30.46 |
|  | 7.69 | 19.52 | 15.82 | 50.46 | 13.45 | 12.00 | 28.54 | 64.67 | 14.29 | 29.97 |
|  | 3.98 | 14.63 | 33.80 | 41.31 | 14.71 | 3.70 | -0.88 | 14.02 | 50.43 | 20.87 |
|  | 25.66 | 2.96 | 13.96 | 15.04 | 43.14 | 41.15 | 0.85 | 29.93 | 9.63 | 29.17 |
|  |  |  |  |  |  |  | 31.85 | 47.75 |  |  |
| Mean | 9.27 | 22.16 | 19.54 | 35.20 | 13.86 | 18.28 | 22.53 | 29.48 | 25.37 | 22.51 |
| Variance | 82.08 | 464.46 | 48.19 | 286.91 | 164.63 | 167.01 | 378.99 | 375.34 | 307.58 | 206.46 |

# APPENDIX D

# DRIVER PERFORMANCE SCORES

DRIVER PERFORMANCE SCORES*

(While driving only)

| | Driving Conditions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J |
| | 1.673 | 4.950 | 2.800 | 4.713 | 3.314 | 3.479 | 2.471 | 5.365 | 3.714 | 2.900 |
| | 3.922 | 3.056 | 3.509 | 4.680 | 3.178 | 2.524 | 3.201 | 4.433 | 3.733 | 3.670 |
| | 2.175 | 2.891 | 5.919 | 5.958 | 3.574 | 2.478 | 3.413 | 4.032 | 5.389 | 4.874 |
| | 2.569 | 3.788 | 5.030 | 5.460 | 5.088 | 2.308 | 4.194 | 7.084 | 6.504 | 3.712 |
| | 2.278 | 4.869 | | 2.983 | 2.263 | 4.742 | 3.595 | 3.952 | 4.341 | 2.485 |
| | 3.056 | 2.272 | 4.172 | 5.772 | 3.104 | 3.411 | 4.927 | 4.189 | 3.752 | 3.559 |
| | 2.197 | 4.642 | 4.793 | 4.840 | 4.334 | 2.753 | 3.444 | 3.832 | 4.282 | 3.306 |
| | 3.448 | 2.252 | 2.894 | 6.394 | 4.069 | 3.290 | 2.005 | 3.633 | 3.388 | 3.379 |
| | | | | | | | 2.965 | 4.387 | | |
| Mean | 2.665 | 3.590 | 4.171 | 5.100 | 3.616 | 3.123 | 3.357 | 4.545 | 4.388 | 3.486 |
| Variance | 0.564 | 1.276 | 1.338 | 1.124 | 0.752 | 0.634 | 0.753 | 1.155 | 1.111 | 0.487 |

*Scores are the mean deviation for each subject measured from the subject's mean lane position. Each unit = 0.223 ft.

DRIVER PERFORMANCE SCORES*

(While driving and reading random numbers)

| | Driving Conditions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J |
| | 2.475 | 4.528 | 2.836 | 6.521 | 4.501 | 3.208 | 4.640 | 5.632 | 3.192 | 3.558 |
| | 3.577 | 2.562 | 3.360 | 5.925 | 3.696 | 3.448 | 4.702 | 5.394 | 3.825 | 3.388 |
| | 2.456 | 3.429 | 6.402 | 5.262 | 3.760 | 3.222 | 4.452 | 4.787 | 5.159 | 4.159 |
| | 3.572 | 4.497 | 4.362 | 7.620 | 4.394 | 4.211 | 4.248 | 5.102 | 5.982 | 5.444 |
| | 2.197 | 4.426 | | 4.898 | 2.785 | 4.946 | 4.345 | 4.933 | 4.632 | 2.692 |
| | 3.055 | 3.505 | 5.469 | 8.422 | 8.282 | 4.241 | 4.617 | 3.897 | 4.957 | 4.499 |
| | 2.919 | 3.892 | 4.082 | 6.114 | 3.700 | 2.782 | 5.159 | 5.665 | 4.275 | 3.777 |
| | 2.755 | 3.341 | 4.304 | 7.320 | 3.725 | 4.630 | 3.236 | 5.235 | 4.366 | 3.980 |
| | | | | | | | 8.549 | 5.462 | | |
| Mean | 2.876 | 3.772 | 4.402 | 6.510 | 4.355 | 3.836 | 4.883 | 5.123 | 4.548 | 3.937 |
| Variance | 0.260 | 0.483 | 1.465 | 1.457 | 2.789 | 0.600 | 2.159 | 0.301 | 0.725 | 0.665 |

*Scores are the mean deviation for each subject measured from the subject's mean lane position. Each unit = 0.223 ft.

# VITA

Florus Gerhardt Gross was born in Springfield, Illinois, on August 8, 1945. He received a Bachelor of Science degree in Industrial Engineering from Virginia Polytechnic Institute in 1968. He is presently completing studies for the Master of Science degree in the Department of Industrial Engineering and Operations Research at VPI & SU.

His work experience includes one year in the Industrial Engineering Division of Eastman Kodak Company in Rochester, New York, five years as Assistant Registrar at VPI & SU, and one year as a graduate research assistant in the IEOR Department at VPI & SU.

F. G. Gross

# THE MEASUREMENT AND COMPARISON OF RELATIVE WORKLOADS UNDER SEVERAL DRIVING CONDITIONS USING A SIMULATOR

by

Florus Gerhardt Gross

## (ABSTRACT)

A secondary task measure was used to evaluate the effects of various automobile handling characteristics on driver workload. The study was performed using the VPI & SU driving simulator, a variable speed random number generator and display, plus other control and recording equipment.

Workload scores for 82 subjects were determined under various combinations of wind and curvature disturbances, vehicle steering gain, and vehicle response time. Driving performance was analyzed to measure intrusiveness of the secondary task and to confirm workload differences.

The results showed definite differences across the levels of combined wind and curvature. These supported the assumption that the secondary task measure would be capable of measuring differences in driver workload. No significant differences in workload scores were obtained for changes in steering gain or vehicle response time. The secondary task did intrude on the primary task, indicating that its use may cause experimental complications. The method and equipment appear to be useable in either simulator or on-the-road vehicles.