Johns, T.R., and Allen, J.A. (1971). Driver License Road Testing Project Report. Chapel Hill, NC: University of North Carolina Highway Safety Research Center.

ATTENTION

The enclosed report is a reprint of the original technical report which has recently gone out of print. Its content does not differ in any way from the original report. The format differs slightly due to time restrictions in the reprinting process.

We hope that this report will fulfill your interests. We appreciate your continued concern in highway safety.

THE UNIVERSITY OF NORTH CAROLINA HIGHWAY SAFETY RESEARCH CENTER
CHAPEL HILL, NORTH CAROLINA

SPECIAL REPORT

TO THE

DRIVER LICENSE DIVISION

DEPARTMENT OF MOTOR VEHICLES

ON

DRIVER LICENSE ROAD TESTING

PROJECT #DL-69-001 (001)

SPONSORED BY

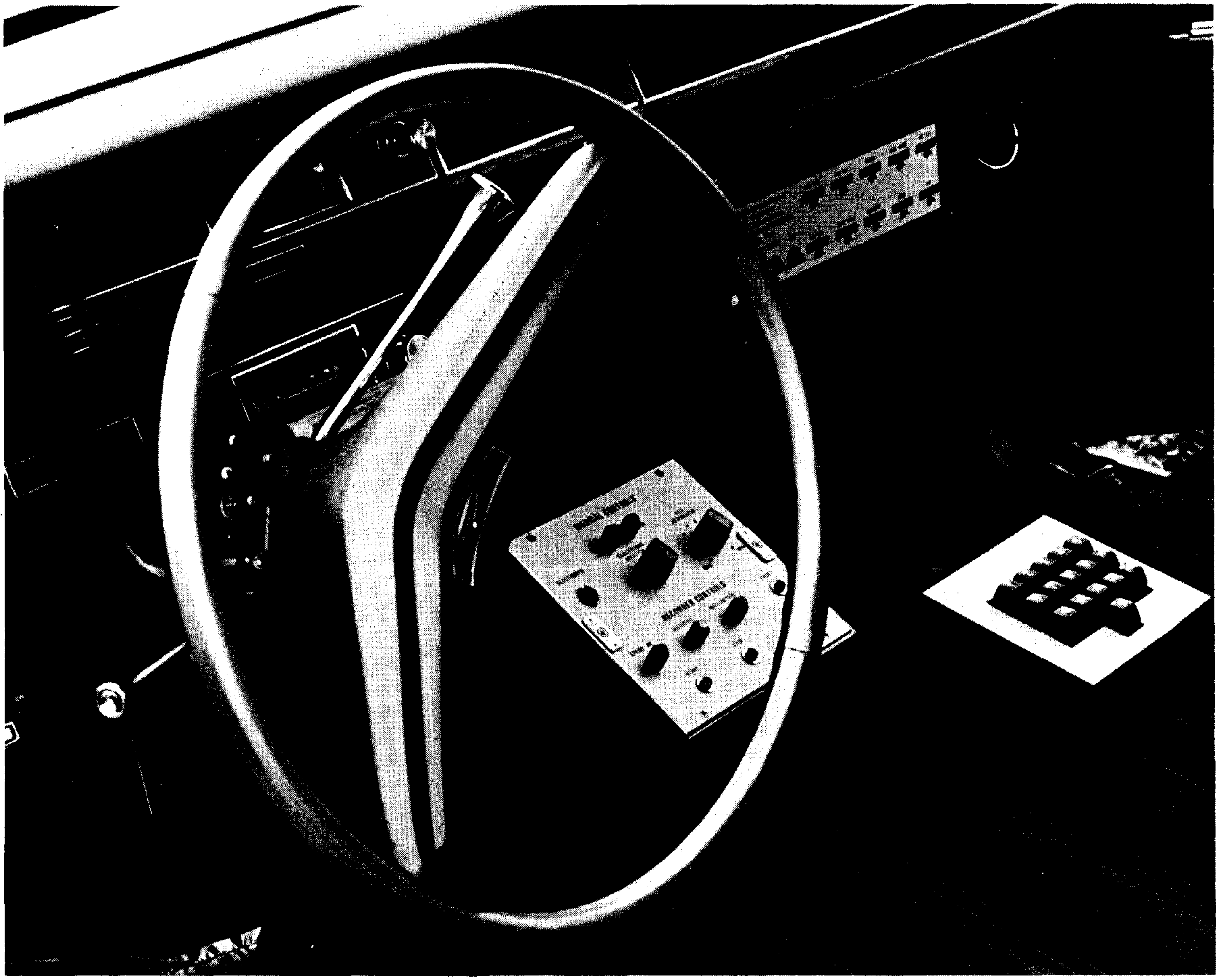
GOVERNOR'S HIGHWAY SAFETY OFFICE

Prepared by
John A. Allen, Jr.

Project Director
Themis R. Johns

October, 1971

UNC/HSRC-71/10/1



Interior of specially equipped vehicle showing original special instrumentation.

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SPECIAL REPORT

TO THE

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SPONSORED BY

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presented by the

UNIVERSITY OF NORTH CAROLINA
HIGHWAY SAFETY RESEARCH CENTER

I. PROJECT SCOPE

In this cooperative project involving the Department of Motor Vehicles and the Highway Safety Research Center, the former provides project direction while the latter, through Dr. B. J. Campbell, provides technical direction. The overall project goal is to improve the quality of special re-examinations now given by the Driver License Division of the Department of Motor Vehicles through use of specially equipped instrumented cars and a training device ("simulator"). Baseline information on many driver classes must be obtained to guide use of these tools.

II. WORK TO HAVE BEEN COMPLETED DURING INITIAL PHASE

1. Instrumented Cars. Survey and evaluate existing models; acquire three cars that meet project requirements and become familiar with their use;

train special license examiners to use them; begin collecting and evaluating data.

2. Driving Simulator and Housing. Survey and evaluate existing or proposed simulators; acquire a simulator that meets project requirements; become familiar with its use; begin collecting and evaluating data.

3. Contractual Services. In addition to the skills and expertise of the in-house personnel, secure professional, analytical, engineering, biomedical, computer, and related assistance in support of this project on a contractual basis.

III. WORK COMPLETED DURING INITIAL PHASE

A. Major Instrumented Car Events and Activities During the Period

During the first year a variety of activities were undertaken by the project. Figures 1 and 2 below show the chronological order of these events. Figure 1 summarizes programs, tests and studies involving the direct use of the instrumented vehicles. Figure 2 summarizes major project events related to staffing, contractual services, reports, etc.

Figure 1. Flow diagram summarizing some of the major first-year events involving the instrumented vehicles.

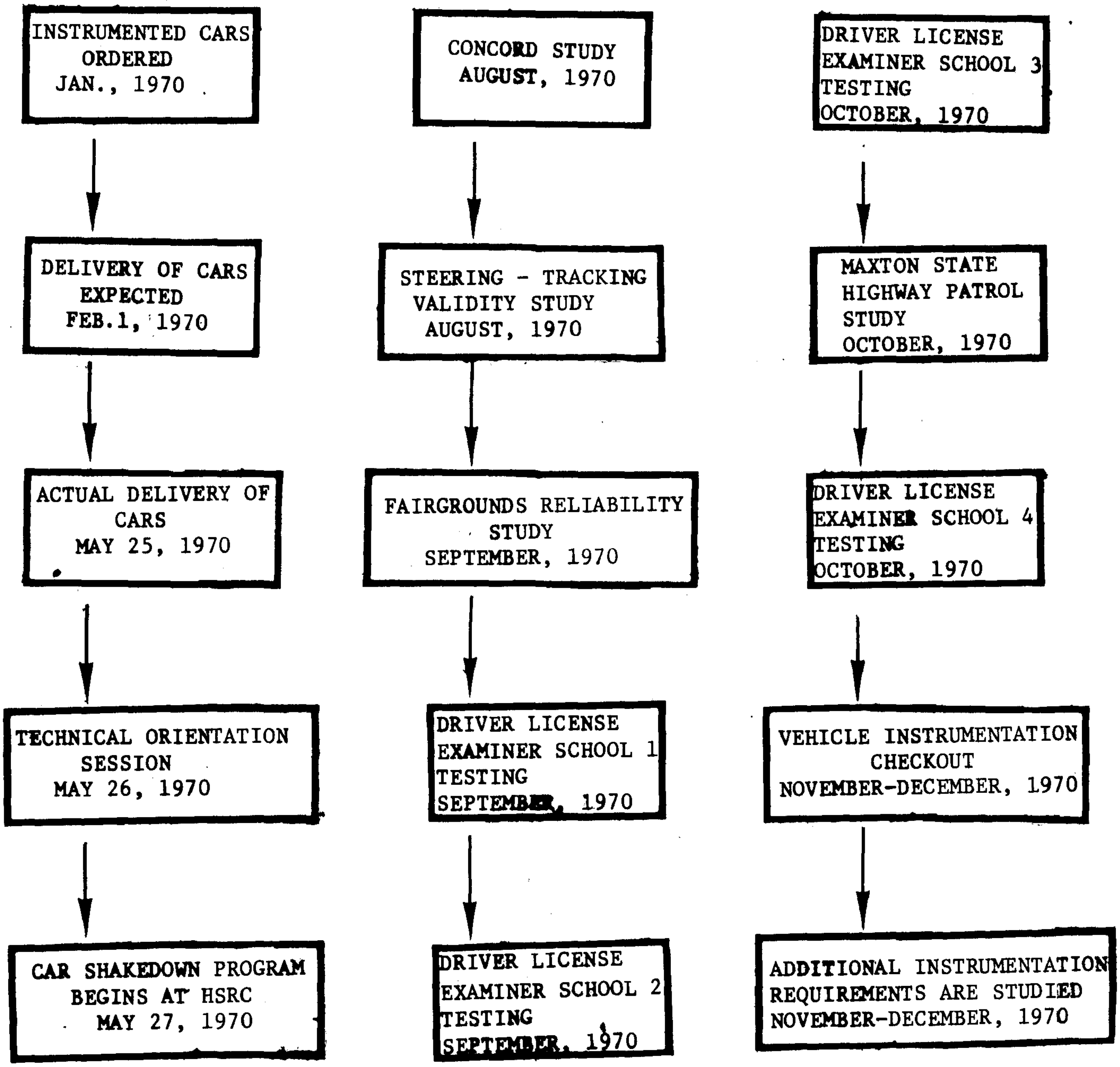


Figure 2. Flow diagram summarizing chronology of staffing and reports during year.

Dr. Themis Johns
Becomes Project Director
September, 1969

↓

Discussions with RTI,
UNC Medical School, and
N. C. State University
Engineering School
Begin
Jan. - March, 1970

↓

Memorandum of agreement for services
with Research Triangle Institute
is executed
February, 1970

↓

Memorandum of agreement with UNC
Medical School is executed
April, 1970

↓

First report from RTI
received by HSRC
April, 1970

↓

Working outline of considerations
for studying and testing, pre-
pared and reported by
Themis Johns of HSRC
April, 1970

Dr. Stan Soliday joins staff
for Summer, 1970
June, 1970

↓

Senior Driver license
Examiners:
Joe G. Mangum
Dan G. McIntyre
Steve M. Parker
assigned to project
August, 1970

↓

Dr. John A. Allen, Jr.
joins HSRC and is assigned to
project
September, 1970

↓

Mr. Edward Itkin, a graduate
student in Psychology joins
project to assist with eye
movement work
September, 1970

↓

Dr. Thomas Rockwell of
Ohio State University
gives eye movement talk
at HSRC
September, 1970

↓

Reports received from RTI
and Dr. Norman Coulter of
the UNC Medical School

Continued

Figure 2. Continued.

Miss Talbot Malcolm, engineer
and student, joins project
October, 1970

↓

List of initial supplementary
instrumentation presented to
DMV by Themis Johns and John
Allen
November, 1970

↓

Proposal to investigate eye
movement characteristics
of drivers received by HSRC
from Dr. Steve Schroeder and
Edward Itkin
December, 1970

↓

Biomedical Engineering and
Mathematics Division of UNC
Medical School assist in calibration
and testing of biomedical
instrumentation--December, 1970

↓

Senior Examiners begin work on
training manual for cars,
rating scale, and begin conducting
and recording data on special
re-examinations--December, 1970

B. Receipt of the Instrumented Cars

During the first quarter of the first grant year, three instrumented cars were ordered from Chesapeake Systems Corporation, Cockeysville, Maryland. Delivery of the vehicles was expected in February, 1970, however, actual delivery was May 25, 1970, and, at that time, official acceptance was made by Mr. Joe W. Garrett, Commissioner of the Department of Motor Vehicles.

Acceptance of vehicles by Mr. Joe W. Garrett. Pictured left to right are: John Lockamy, Assistant Commissioner, Department of Motor Vehicles; Joe Garrett, Commissioner, DMV; John Freeland, Chesapeake Systems Incorporated; and Bill Penny, Assistant Commissioner, DMV.

On May 26, 1970, a five-hour technical orientation session was held at the Department of Motor Vehicles for the purpose of familiarizing those associated with the project on the proper operation of the cars. The session was attended by personnel from the Department of Motor Vehicles, Highway Safety Research Center, Research Triangle Institute, and the University of North Carolina Medical School.

On May 27, 1970, the three cars were turned over to HSRC for shakedown.

C. Literature Review

Prior to delivery of the cars, an extensive review of the research literature was begun on the use of instrumented vehicles in the driver licensing field. The review revealed that little research had been done in the area. However, all research pertinent to the field was reviewed. Work by Greenshields and Platt (1967) at Ford Motor Company was found to be most relevant to the goals of the present project. Their aim was to differentiate drivers on the basis of objectively measured driving patterns over a prescribed course. They reported some success with their method of using empirical procedures to differentiate extreme groups of drivers. The literature review also revealed that other investigators are concentrating on such part tasks or components of the total driving tasks as (1) tracking, (2) gap size preference, (3) car following, (4) visual search patterns, (5) alcohol effects and (6) fatigue effects. A high priority was assigned to the task of assimilating these scattered, fragmentary findings and incorporating them into the overall plan for using the instrumented cars in the driver licensing process.

During the year, the project staff reviewed new reports in the area in an effort to keep abreast of developments in the field. (NOTE: As part of their working contract with the project, the Research Triangle Institute aided in the review of the literature. In their first report, they included a review and discussion of the pertinent work begin done in the area. A copy of this paper can be found in Appendix A.)

D. Exploratory Studies During the Initial Period

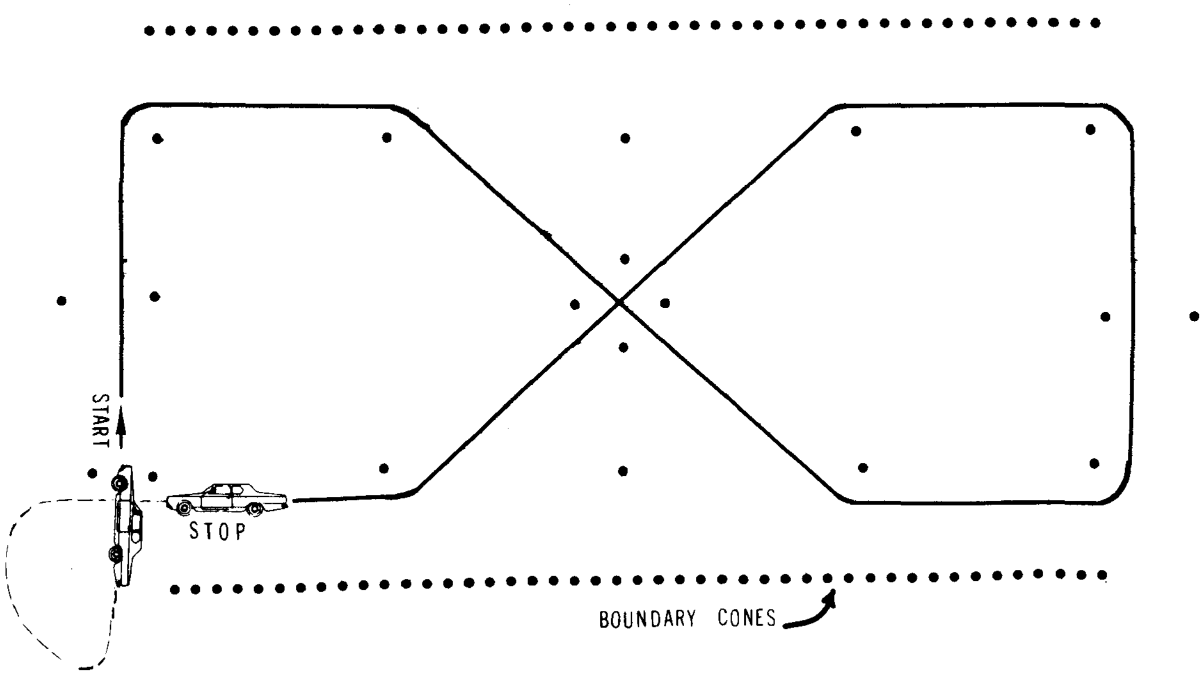
During the latter part of the first year, eight exploratory studies were designed and carried out. Major objectives of these studies were: (1) to assess the validity and reliability of the instrumentation in the instrumented cars, (2) to explore the extent to which various vehicular and driver measures might be used to differentiate drivers with widely different driving skills, (3) to begin obtaining baseline data on groups of drivers differing widely in their driving abilities, and (4) to investigate the relationships between the various control response variables such as braking, steering, accelerating, etc.

1. Concord Study

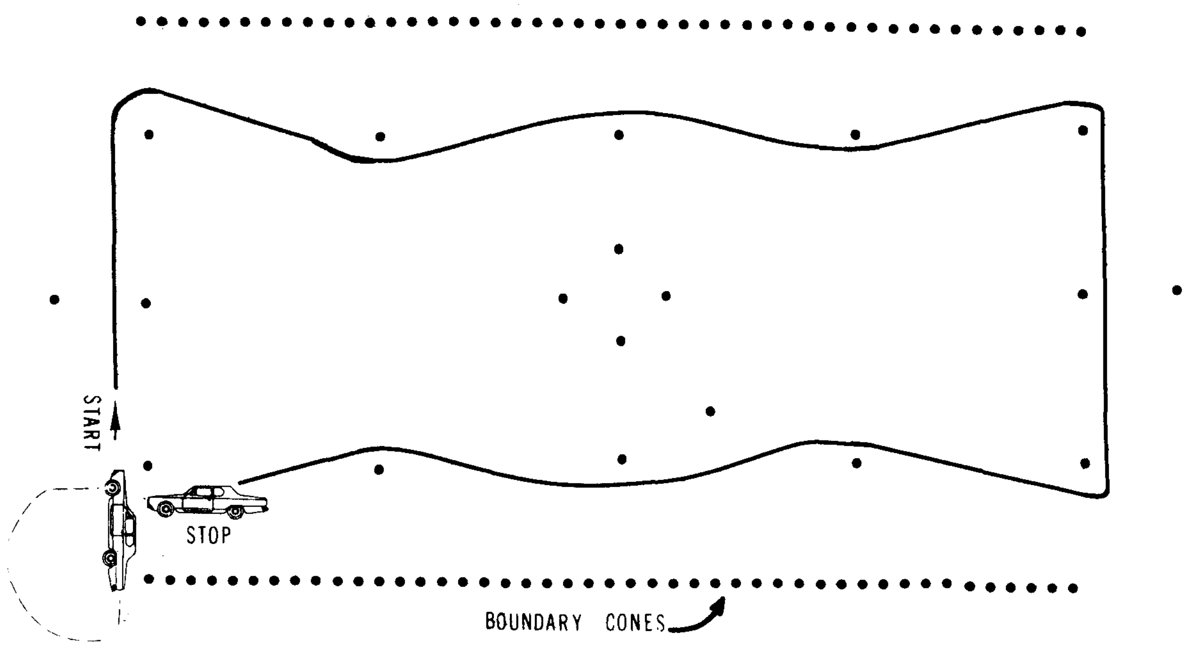
During the week of August 10, 1970, HSRC and DMV staff members associated with the instrumented car project traveled to Concord, North Carolina for the purpose of testing Driver Education Representatives at their annual workshop. Prior to testing, Dr. Themis Johns presented film slides and printed material to all participants, and briefed them on the instrumented cars and the overall goals of the project. Following the briefing, three days of testing were begun. During the testing, novice driving students and Driver Education teachers drove an instrumented car over two test courses. The major question of interest in the study was: Will wide differences in driving experience result in measurable differences among the instrumented car measures?

Each subject-driver drove one car, with one experimenter, on one of the three days, at a particular time of day, over both a closed and open course. The open course consisted of a 3.75 mile (approximately) loop of two-lane, asphalt, secondary roadway with low traffic density. The closed course consisted of 3 configurations (a Figure-8, Weave, and U-turn); each of which was driven twice by each subject-driver. Schematic drawings of each of the closed course configurations are shown in Figure 3 below.

CLOSED TEST COURSE No. 1
"FIGURE 8"



CLOSED TEST COURSE No. 2
"WEAVE"



CLOSED TEST COURSE No. 3
"U-TURN"

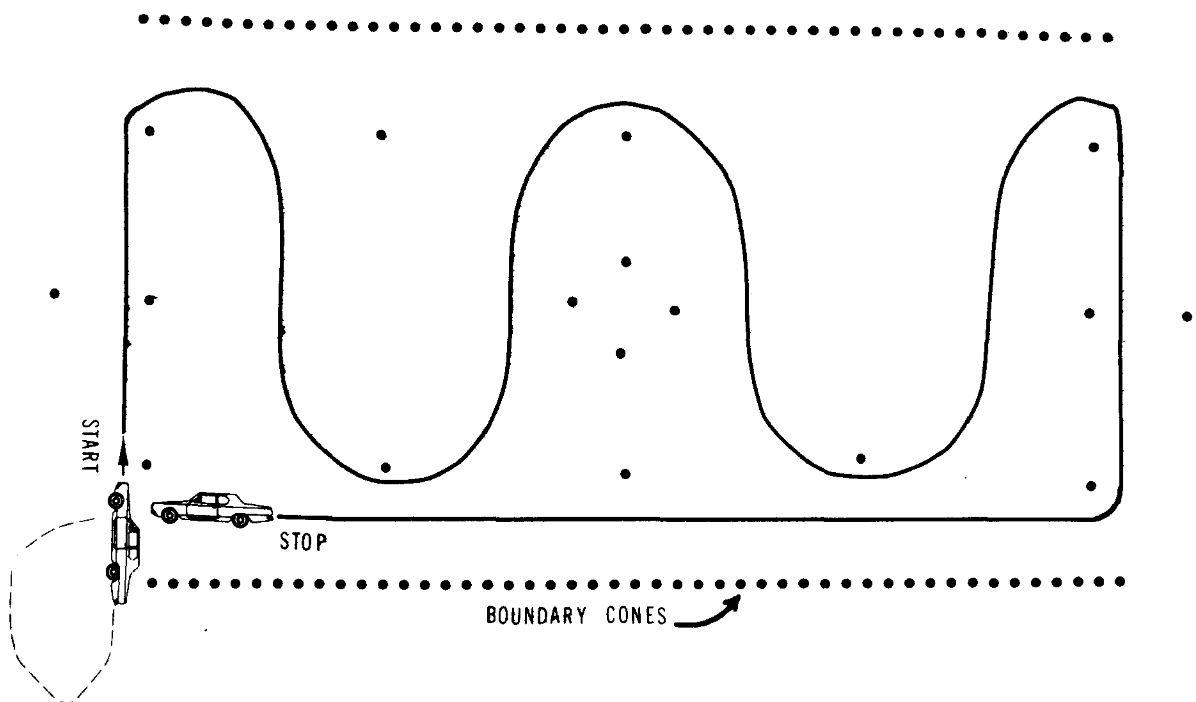


Figure 3. Scehmatic diagram of closed-courses at Concord, North Carolina. Thirty-nine Driver Education Representatives and 12 novice student drivers drove through the courses. Both counter and tape data were collected.

Although analyses are still being performed on the data from the study, statistical analyses of the fine-steering reversals (2° steering movements) of subjects indicated that of the three closed courses, the U-turn configuration differentiated inexperienced and experienced drivers best, followed by the Figure-8 course. Driver groups could not be differentiated on the basis of their fine-steering movements during the Weave maneuver. (Analyses were done on data taken from the vehicle counters.) The data analyses also revealed that, within the open course, novice student drivers used more fine-steering movements than their experienced counterparts. (A contrary finding was revealed in the analysis of Maxton data over a closed course. The Maxton data is reported below.)

Several analyses designed to determine whether or not the three vehicles were measuring the driver-control variables (i.e., steering, braking, accelerations, etc.) in the same way were also accomplished. These analyses revealed that the timers in the cars were not operating the same way. Specifically, it was learned that timing in the red instrumented car was inaccurate below approximately 7 mph. (See Table 1 below.)

Table 1. Mean running time for each of the instrumented cars over the closed course configurations. (Actual driving time for all three vehicles was approximately 3 1/2 minutes)

INSTRUMENTED CAR	AVERAGE DRIVING TIME
GREEN	3.29 minutes
RED	1.69 minutes
WHITE	3.53 minutes

However, this inaccuracy was significant only on the slower, closed course, since during the open course drive, speeds were well above 10 mph. This recording error was later corrected by the Chesapeake Systems Corporation engineer.

2. Steering-Tracking Validity Study

In an attempt to determine how fine steering reversals are related to the position of the instrumented car on a roadway, a simple study was conducted by HSRC at the North Carolina State Fairgrounds.[1] In this study, a

[1] Directed by Dr. Stan Soliday, Associate Professor of Industrial Engineering at N. C. State University.

number of DMV and HSRC personnel were tested on an isolated network of "streets" located in the fairgrounds. Each driver was asked to keep the car on a straight line course as closely as possible. All three instrumented cars were used. Measurements relating vehicle position to the roadway were taken after each drive by "Ph.D.s on down" stationed along the course. Numbers of fine steering movements indicated on the vehicle counters were also recorded.

Correlations were then calculated between fine steerings and roadway-position measurements in order to determine the relationships between the variables. The results indicated that some of the drivers drove a very straight-line course, whereas others did not. Furthermore, in the former group, two classes of "steerers" were identified. That is, some drivers employed numerous fine steerings to achieve a straight-line drive, whereas others used very few steering movements to achieve an equally straight drive. Although the meaning of these findings is not entirely clear, the results do support a tentative theory of steering behavior proposed by Themis Johns at HSRC.

3. Reliability Study at the N. C. State Fairgrounds

During the second and fourth weeks of September, 1970, a vehicle reliability study was conducted at the N. C. State Fairgrounds. (Since instrumentation problems were encountered in the Concord study, a check of the vehicular instruments was felt necessary.) The major purpose was to determine to what extent and for which variables, differences exist between the instrumented cars and between experimenters. An additional aim was to investigate group, order, and driver effects.

In the study, volunteer drivers from the Department of Motor Vehicles were tested by the three Senior Driver License Examiners assigned to the project.[2] Three drivers, at a time, were tested each in a different instrumented vehicle. Each subject-driver drove 3 times around a .33 mile paved 4-block section of fairground streets in an essentially figure-8 pattern that provided for an equal number of right and left-hand turns. Each driver drove the course three times, each time with a different experimenter and car. A total of 24 subjects were run. (Note: A schematic diagram of the course laid out on the fairground streets is shown in Figure 4 below.

[2]Mr. Joe Mangum, Mr. Dan McIntyre and Mr. Steve Parker served as experimenters.

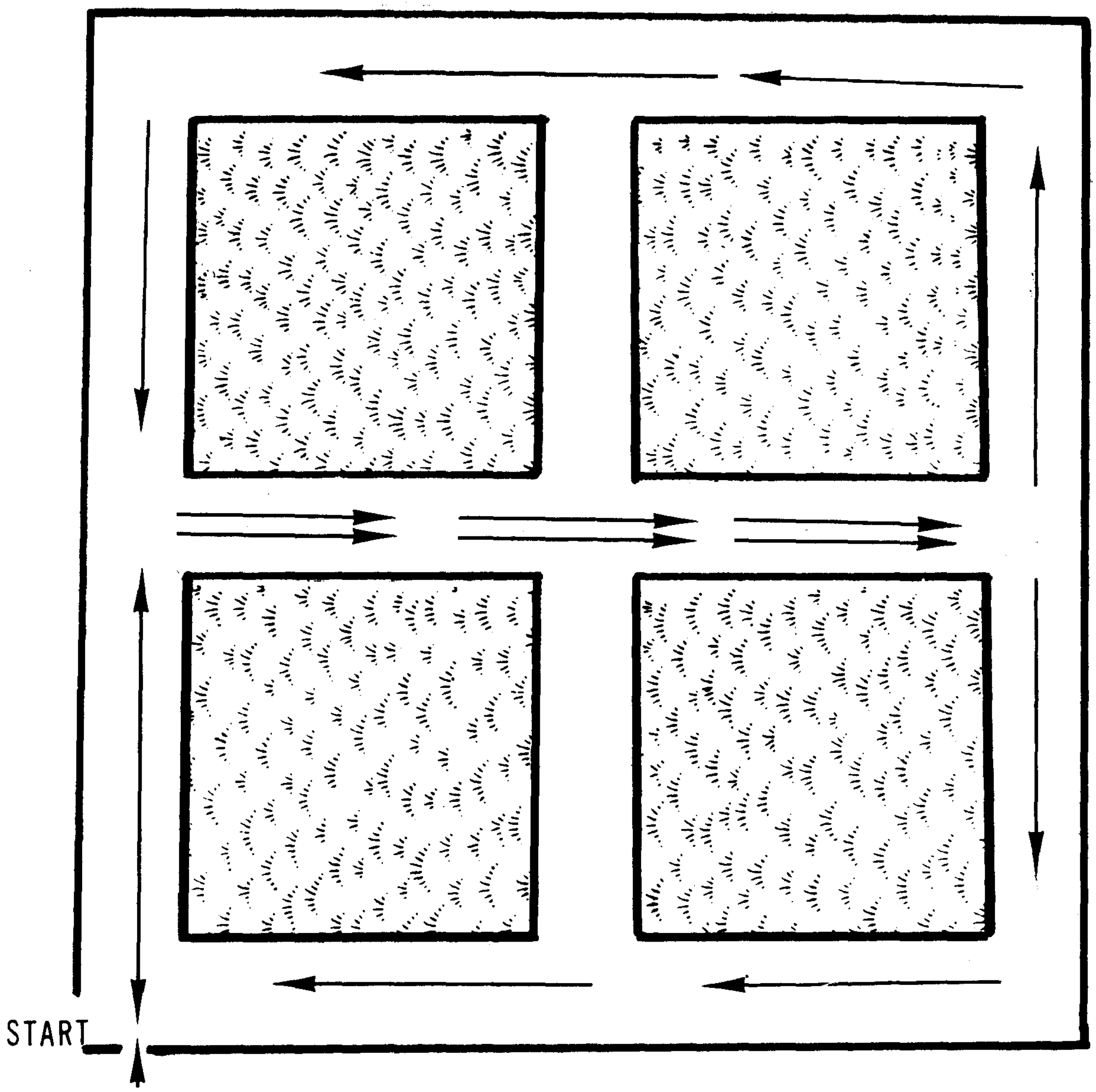


Fig. 4. Schematic diagram of the course used at the N. C. State Fairgrounds.

Analysis of the data revealed that the instrumentation in the cars recorded the driver-control variables somewhat differently. Highly significant differences were found between cars for fine-steering, coarse steering, speed change, and accelerator reversals. These differences indicated that the instrumentation in the vehicles was not recording the same variables in similar ways, a serious problem indeed. However, other analyses revealed that there were no appreciable differences between experimenters. That is, it did not matter who served as experimenter. Also, no group effects were found, indicating that in accordance with the basic experimental design, subjects were indeed randomly assigned to driving times, cars, and experimenters.

A particularly interesting result was the finding that subject-drivers demonstrated a "practice effect." That is, over trials (or time) drivers made fewer numbers of fine and coarse steering movements. For example, as subjects proceeded from one trial to another, their fine and coarse steering adjustments became fewer in number. This is illustrated in Figure 5 below. As can be seen, from trials 1 to 3, the percent change in fine and coarse steering from the previous trial increased; an indication that as drivers proceeded through the test over time, relative numbers of fine and coarse

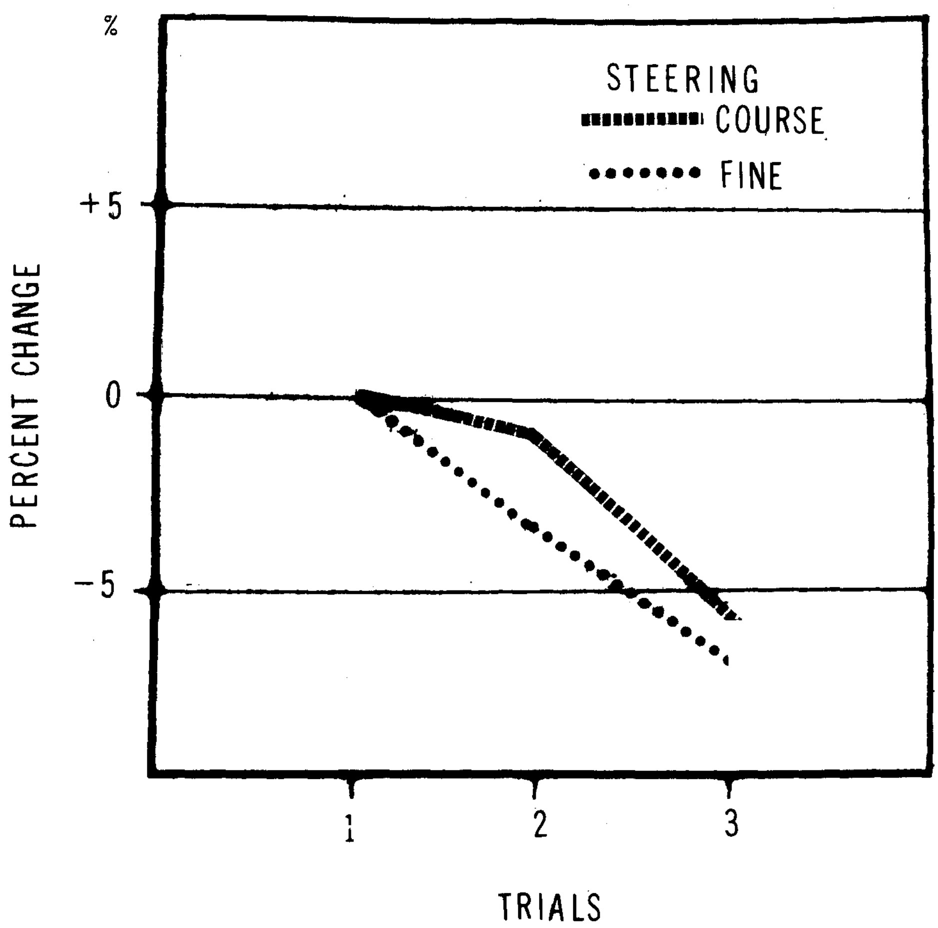


Fig. 5. The "practice effect" of fine and coarse steering maneuvers demonstrated by Fairground drivers. (Per cent change from baseline.)

steering corrections decreased. Whether or not such practice effects indicate a move toward "safer" or "just more relaxed" driving is an interesting question, and one which certainly deserves further study.

4. Driver License Examiner Schools 1 and 2

During the fourth quarter, Driver License Examiners from around the state were tested by DMV and HSRC personnel during the week of their In-Service Training School in Chapel Hill. Since there were four schools during the quarter, four separate testing sessions were conducted.

Examiners tested during Schools 1 and 2 drove one of two courses. One group was required to drive over both a closed course laid out on the UNC physical plant parking lot, and also a section of open road. The other group was tested on an open-road course laid out along residential streets in Chapel Hill (Greenwood Course). For the first group, the major purpose of testing was to determine the relationships among recorded variables over two different kinds of courses--closed and open road. For the second group, the major purpose of testing was to acquire data over a standard course from drivers oriented toward safe and correct driving for future comparison with the data from other classes of drivers.

Preliminary analyses of the data from Schools 1 and 2 revealed that during the closed-course phase, the red and green vehicles were not recording running times and speed-changes in the same way. An examination of the mean running times for the two cars revealed that the "red" vehicle times were significantly lower than those of the green car. Similarly, an examination of the speed-change data from the two vehicles revealed that speed-change in the two vehicles was not being recorded in the same way. That is, the red vehicle values were consistently lower than those of the green vehicle.

The discrepancies reported above were later found to be due to "hardware" problems in the vehicles. They were subsequently repaired by the Chesapeake Systems engineer.

Testing for the third and fourth Examiner Schools was quite different from that for Schools 1 and 2. For drivers in School 3, a three-segment open-road course was driven. The course consisted of a drive from the Institute of Government to the Greenwood Course, a drive through the Greenwood Course, and then a drive back to the Institute of Government. The major purpose of this testing was to collect data on a three-segment open-road course for purposes of assessing the effects of medium and low density traffic on driver's responses.

The purpose of testing during the fourth Examiners' School was to gain insight into the ability of drivers to determine the overall dimensions and overall spatial orientation of the vehicle, and to correctly change orientation, with respect to fixed boundaries. Testing was carried out on 2 closed courses laid out on the UNC physical plant parking lot. Drivers drove one or the other of the two courses depending on their group assignment.

Statistical analyses of the data from these studies are currently in progress.

5. Maxton Study

When the North Carolina State Highway Patrol traveled to the Maxton-Laurinburg airport to conduct their high-speed driver training exercises, personnel from HSRC and DMV were on hand to test SHP veteran and rookie drivers over a closed driving course. Testing was accomplished over a two-day period. The major purpose of the study was to explore the capability of recorded variables to differentiate two groups of professional drivers--veterans and beginners.

On the first day of testing, each of 12 veteran drivers drove one of the instrumented vehicles over a series of eight test configurations. The following day, 12 beginners drove the same eight configurations. Another 21 beginners drove over 6 of the configurations. The test consisted of a lane-changing maneuver (both forward and backward), a circling maneuver (requiring both right and left hand turning), a straight-line acceleration and stop, a backing drive and stop, and two configurations which required the driver to crush markers with either the front or rear tires. A parking test was also included. (See Figure 6 below.)

Preliminary analyses indicated that, in general, rookie drivers made somewhat fewer fine-steering adjustments (although not significant) than their veteran counterparts. See Table 3 below. (This finding is opposite to that found for novice and experienced drivers on the open course at Concord.) This was found to be particularly true during the straight-line acceleration and backing maneuvers. However, whether this finding reflects

Table 2. Mean fine-steering adjustments for veteran and "rookie" SHP drivers during Foreward and Backing maneuvers.

	VETERANS	ROOKIES
FORWARD	14.25	13.51
BACKWARD	28.92	26.44

"real" characteristic driving differences between rookies and veterans remains to be seen. Additional analyses of these data are in progress.

E. Data Reduction and Computer-Based Statistical Analyses

During the first quarter of the initial grant year, discussions were undertaken with Ford Motor Company and Chesapeake Systems with regard to data reduction and computer programming. From these discussions, we learned to our dismay that Chesapeake had made a design change in the cars' instrumentation, and as a result tapes from the vehicles could not be processed by Ford's existing Highway Systems Research Car data reduction programs. Furthermore, at that time, Chesapeake Systems Corporation did not have the capability for procesing the data. Chesapeake Systems informed HSRC that more time would be needed for "debugging" and improving their program before they could offer a "packaged" data reduction service.

The absence of tape data and computer processing severely handicapped the project during the year. As a stop-gap measure, analyses were performed on the data taken from the car counters. However, this proved totally unsatisfactory because manual recording and analyses of the data was required.

It is felt that some valuable information was gathered from these analyses, however, despite the labor requirements. By the middle of the fourth quarter, Chesapeake Systems began offering a data-reduction service to the project. However, because their programs still were not completely "debugged", the early tape data was only of marginal value.

To solve these problems, arrangements were made with the UNC Biostatistics Department to assist HSRC in: (1) developing a locally-based, data reduction capability for the tape data, and (2) creating a special package of computer programs for the statistical analysis of counter and tape data. By the end of the initial grant period, the project had an operational data reduction program of its own.[3]

[3] In September, 1971, Mr. Jim Kitchen, joined the HSRC programming staff and was assigned the tasks of 1) upgrading the basic data reduction program and 2) creating a special package of statistical programs for the project data.

F. Data Manual

In an effort to facilitate the organization of data from the project, and thus provide a ready reference for those doing statistical tests on the data, a DATA MANUAL was developed by the project staff. Several sample pages from the manual are included in Appendix F. The manual is divided into two major sections: (1) a General Information ection, and (2) Study sections. The General Information section contains an introduction to the general problem of reducing the data of the project, flow diagrams depicting the movement of data from collection to analysis, and information concerning the proper formats to be used in coding and keypunching the raw data from both the automobile counters and tapes onto IBM cards. Information regarding the status and location of the project tapes used in the instrumented cars is also included in the General Section of the manual.

Specific information about each experiment conducted by the project is also included in the manual. A specific section is assigned to each study. Each of these sections contains a statement of the major purpose or objective of the study, an outline of the method and procedure used, and a listing of the major factors of interest in the study. A schematic diagram of the experimental design used is also included.

The manual will be used by the project staff members and others involved in reducing the "numbers" collected in the course of the project into meaningful information. The "one-source" nature of the manual has already proven to be a valuable asset to the project, because an investigator or statistician can find in one book all of the information necessary to understnad the design structure of a particular experiment and proceed with the statistical analyses.

G. Supplementary Instrumentation

Throughout the grant period, a great deal of time and attention was given to consideration of additional instrumentation for use in the vehicles. Early in the year, careful thought was given to the possibility of acquiring an eye movement monitor suitable for obtaining eye movement information from drivers within the instrumented vehicles. To aid in this search, Dr. Stan Soliday of N. C. State University was engaged during the summer of 1970. Dr. Soliday reviewed and evaluated previous eye movement studies and techniques, and determined what kinds of eye monitoring devices were available. A copy of this report was received by HSRC on October 9, 1970, and can be found in Appendix D.

Recommendations:

(1) Determine eye movement patterns of drivers in controlled environments, such as those found in the laboratory.

(2) Determine whether the eye movements of experienced and inexperienced drivers differ significantly.

(3) If differences are found to exist between these drivers, train "poor" drivers to change their basic eye movement patterns in the direction of those found to be characteristic of "good" drivers.

(4) An automatic data reduction capability is a necessity regardless of the type of measuring unit that is acquired.

(5) If possible, lightweight photoelectric devices such as the Honeywell Remote Oculometer should be considered in preference to heavy and cumbersome head-mounted devices such as the Mackworth-type eye movement camera.

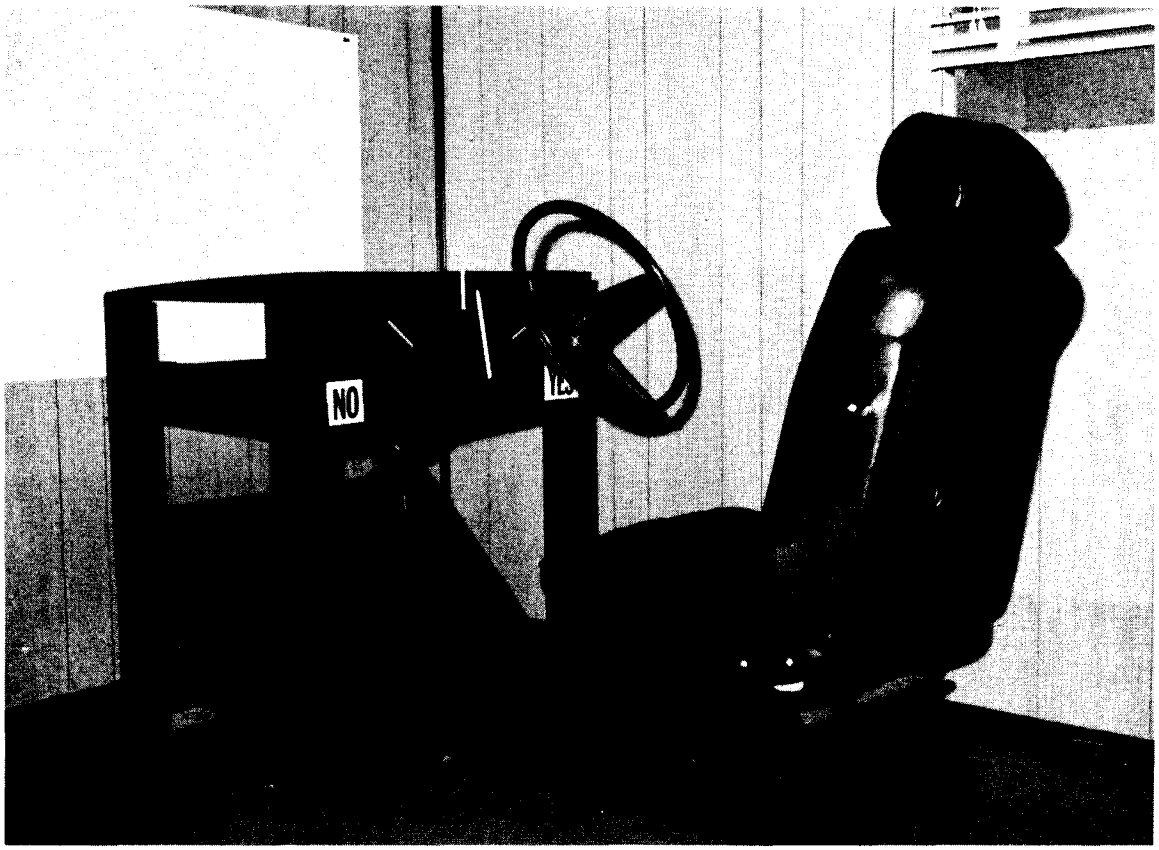
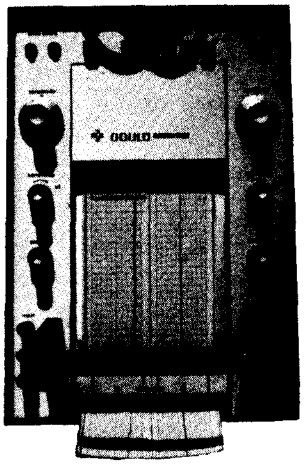


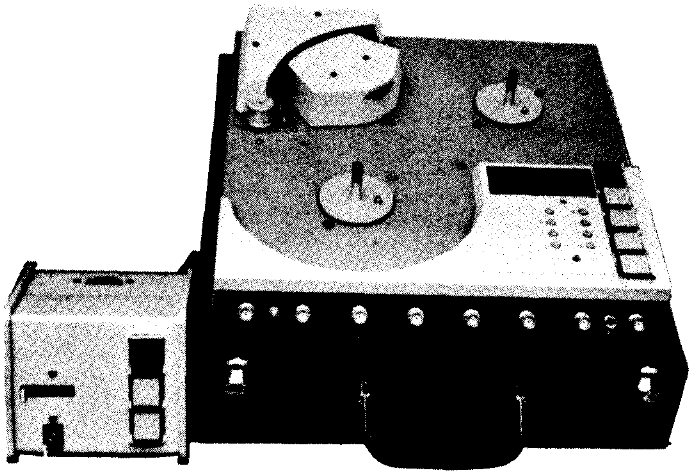
Figure 7. Highway Safety Research Center Laboratory.

Figure 8. Davie Hall Laboratory, Psychology Building.

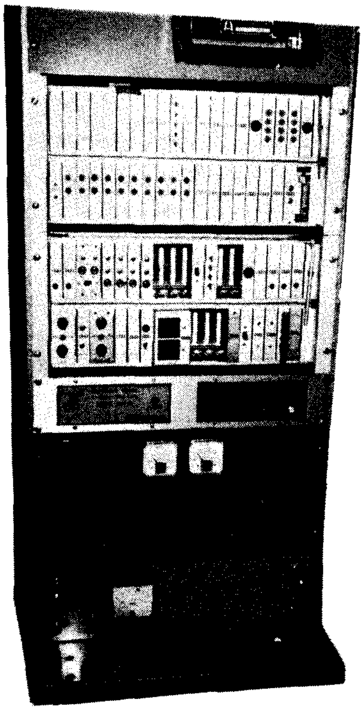


Brush 220

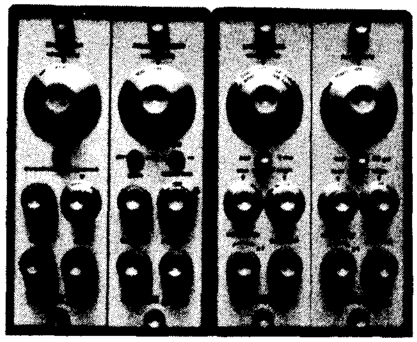
Oscillographic Recorder



Lockheed FM Analog Recorder



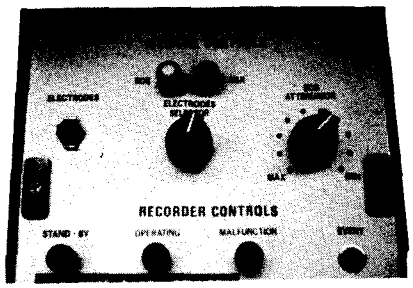
BRS Forringer Logic Equipment



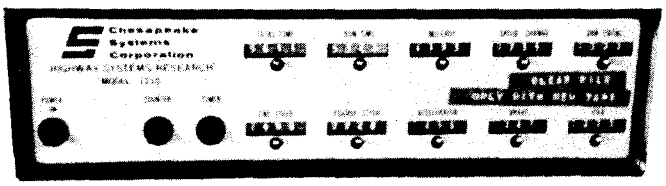
Brush Signal

Conditioning

Equipment

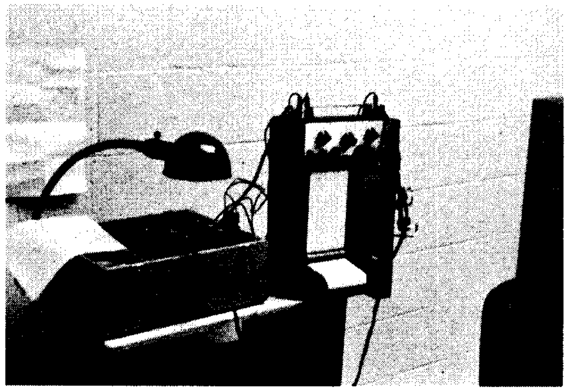


Chesapeake Systems Medical Control Panel



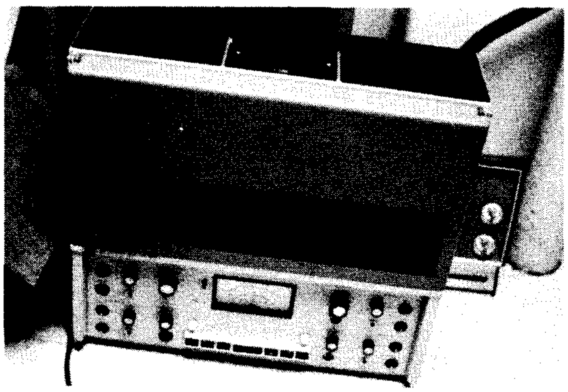
Chesapeake Systems Control-Response Counters

Figure 9. H.S.R.C. Equipment .

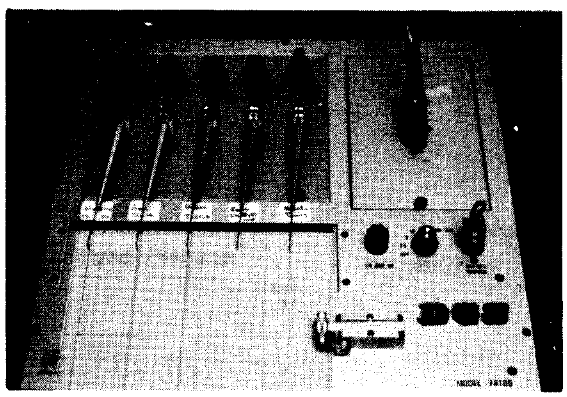


Biometric Eye Movement Monitor

Techni-rite Oscillographic Recorder



Hewlett Packard FM Recorder



Lafayette 5 Channel
Oscillographic Recorder

Figure 10. Davie Hall Equipment.

In an effort to acquaint members of the HSRC staff with some of the current work being done in the eye movement area, Dr. Thomas Rockwell of Ohio State University was invited to present a review of his work. The presentation was held during the first week of September 1970.

On September 14, 1970, Mr. Edward Itkin was engaged on a part-time basis to assist with the eye movement investigations. During the fourth quarter, Dr. Stephen Schroeder of the UNC Department of Psychology and Mr. Itkin formed a plan to investigate characteristics of eye movements as they relate to the road testing of drivers. It was proposed that most of their initial work will be carried out in a special laboratory space in the Department of Psychology in Davie Hall.

In addition to the eye movement apparatus, consideration has also been given to the incorporation of additional instrumentation into the vehicles. During the fourth quarter, a list of recommended supplementary instrumentation was prepared and presented to the Department of Motor Vehicles. The selection of the first items was initiated with the approval of the Department of Motor Vehicles. A significant feature of the instrumentation is its portability which makes it usable either in the instrumented cars, subject's personal vehicle, or in the HSRC laboratory. Photos of several pieces of this equipment are shown and described in figures 7, 8, 9, and 10 below.

Since one of the major tasks of the HSRC staff will be to identify important vehicular and driver variables, which hopefully will allow differentiation of drivers, careful consideration has been given to instruments which, by their good design, make a large screening process such as the one anticipated manageable.[4] Some of the variables to be measured include heart-rate, EEG (Brainwave patterning), temperature, roadway position of the vehicle, brake force, etc.

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[4]Since the initial draft of this report, both the Davie Hall and HSRC laboratories have become fully operational. During July and August, 1971, both laboratories were involved(together with the UNC Center for Alcohol Studies) a pilot study concerning the interactive effects of nonprescription drugs and alcohol. Much of the instrumentation described above was put into use at that time.

H. Driving Simulator

During the first and second quarters of the first year, the HSRC staff continued its search for a driving simulator. Numberous contacts and discussions with possible vendors were undertaken. Both existing and projected devices were considered.

In brief, it was learned that a complete and suitable simulator could not be purchased off-the-shelf with the funds available ($100,000). Proposals from two major vendors ere evaluated during the first quarter; (1) Singer's Link Group Division, Binghamton, New York, and (2) Gemco, Inc., Tulsa, Oklahoma. The estimated cost of the Link Group system was $135,000 plus an additional $200,000 for a 20-minute film, whereas the less sophisticated Gemco system was priced at $100,000 excluding film and related software which would add another $101,200. These costs clearly placed purchasing at that time out of reach.

Since the major costs of a simulator were found to be largely for research and development, a plan by which several states could share the burden of such costs was initiated by HSRC. During the second quarter discussions with several area states, with simulator requirements similar to those of North Carolina, were begun. It was hoped that some agreement could be reached such that the one-time purchase cost per state would be reduced, thereby placing the overall costs within current budgetary funds. To this end, discussions with officials from other states were begun regarding a possible meeting to discuss common goals and cost sharing. However, it became clear that such a meeting could not be arranged.

Since it was determined that a suitable driving simulator could neither be purchased off-the-shelf nor developed for the $100,000 allocated, a new approach was proposed for the new grant year. In brief, a year-long study will be undertaken to determine whether it is feasible for North Carolina to consider developing (in a building-block fashion) a computer-based driving simulator of its own. In this way, a simulator system could be developed and expanded over a period of years, the major advantage being reduced research and development costs in any one period.

Contractual Services

Early in the first grant year agreements with The Research Triangle Institute and the University of North Carolina Medical School were executed, thereby securing their participation in the overall task of planning for the use of the instrumented cars. The Research Triangle Institute was charged with the responsibility of a) reviewing the existing literature, b) considering supple-mentary instrumentation for future use, and c) defining the procedures for acquiring baseline data--including procedures, test courses, etc. Three reports were prepared and received from RTI regarding these tasks. (See Appendices A, B, and C.)

Throughout the year, the Biomedical Engineering and Mathematics Division of the UNC Medical School acted as a consultant to the Highway Safety Research Center and assisted in calibrating and establishing the reliability of the biomedical instrumentation used in the vehicles. A report was also prepared dealing with suggestions for supplementary instrumentation, suggestions for test courses and collection of baseline data, and possible answers to the general question: "How can drivers be discriminated?" A copy of the report can be found in Appendix E.

On September 1, 1970 and July 1, 1971 respectively, Dr. John A. Allen, Jr. and Dr. Douglas Neil joined the HSRC staff and were assigned to the project.

APPENDIX A

USE OF INSTRUMENTED CARS IN THE DRIVER LICENSING FIELD*

*Prepared by A. R. Schleicher, Research Triangle Institute Operations and Economics Division, and submitted to the Highway Safety Research Center.

ADAPTATION OF THE HIGHWAY SYSTEMS RESEARCH CAR FOR USE IN A TESTING PROGRAM BY THE HIGHWAY SAFETY RESEARCH CENTER

I. SUMMARY

Review of the literature concerning the use of instrumented cars for driver performance testing has shown that research in this field in the United States has been dominated by the use of the Highway Systems Research (HSR) Car and the concepts embodied within it. A relatively limited amount of validation testing has been done concerning the basic premises involved in the use of this vehicle. The limited results have, however, been published, republished, and rearranged into a considerable volume of literature. The sample sizes employed in driver analyses utilizing the HSR vehicle have been too small to make sweeping conclusions concerning either the validity of the basic concepts involved in measurements with the test vehicle or the ability to correlate results with future driver performance. The current HSR unit, manufactured by Chesapeake Systems Corporation, gives simple counts and rates of motions of the vehicle controls by the driver. The actual responses of the vehicle and its road trajectory are not indicated. With certain models of the HSR Car, two physiological measurements are made, i.e., heart rate by means of the electrocardiograph (ECG), and galvanic skin response (GSR). These two physiological measurements do not appear to have been proven particularly significant, although certain vague claims and generalizations are made concerning the usefulness of the data. The difficulties in analytically justifying

the measurements made by the HSR unit (and all other test vehicles) are due in great part to lack of a fundamental knowledge of the driving task and the specific relationship of task factors to safety.

Certain English and European workers have taken quite a different approach to the use of an instrumented car for driver testing. These workers tended to measure the actual actions of the vehicle and ignore the minor physical responses of the driver himself. There is little reported data on this approach; however, some of the measurements and techniques used appear worthy of at least further consideration.

It remains to be established whether the HSR vehicle with or without additional data gathering equipment is a satisfactory tool for evaluating driver license examinees. It is also necessary to determine if the HSR method does indeed discriminate certain classes of drivers, whether or not the discrimination can be used as a predictive technique for beginning drivers or drivers undergoing some type of rehabilitation or retraining, or whether the method can merely statistically indicate in which category a driver presently falls. It is recommended that the Highway Safety Research Center consider making more quantitative measurements (as opposed to the current qualitative HSR measurements) of driver actions and vehicle responses. It seems imperative that a large sample of drivers should be included in the test program and that the behavior of these drivers be followed for as long a period of time as practical. In addition, retesting of drivers should be done after a time lapse. More consideration should be given to the use of control groups and to insure that the results of testing drivers are not biased by previous knowledge of the driver's characteristics, as may have been the case in some of the earlier work. It is desirable to conduct the driver testing experiments under as closely controlled conditions as possible. Ultimately, this may involve the use of the HSR or some other instrumented vehicle on a special test ground or instrumented track course. Such a special course could provide both flexibility and repeatability of quantitative measurements of driver actions in response to controlled situations.

Literature concerning the use of driving simulators was examined only incidentally to review material concerning instrumented cars However, the observation was made that the development of a realistic simulator for driver training or testing is an extremely complex and difficult problem. In some respects, the simulator problem is much more difficult than an aircraft-type simulator. This is because driving situations frequently involve at least three bodies: the driver's vehicle, the earth (or fixed surroundings), and other vehicles or pedestrians. Simulation of the relative motions of the three or more bodies with only one motional relationship being under total control of the driver is very difficult, particularly with two-dimensional presentation situations, such as screen projection techniques. Another problem is identical with that for the instrumented car, namely, that the critical processes of driving and their relationship to safety have not been precisely defined.

It appears feasible to take the data tapes recorded by the HSR equipment with or without additional instrumentation and process them on local computer equipment, either with existing or new analysis programs as desired. All that is necessary to read the tapes on a local computer is to analyze the data format as presented on the magnetic tape from the HSR unit. When the HSR unit is actually on hand, manipulation of the various controls to generate known sequences of data should make analysis of the data tape format relatively simple. Additional detailed suggestions for improved instrumentation and its use must await familiarization with the actual HSR unit and careful examination of both the installation, the electronic components, and their circuit layout.

II. REVIEW OF LITERATURE CONCERNING THE HSR AND OTHER INSTRUMENTED CARS

The Highway Systems Research Car appears to be the only vehicle instrumented for driver performance measurements which has received appreciable attention in this country. The HSR vehicle in its current form is the result of 25 years of experimentation and development by Greenshields and Platt [Ref. 1]. The basic instrumentation which evolved into the present HSR vehicle was the Drivometer. The original Drivometer used inertial measurements to measure the variation of the test car's trajectory plus instrumentation to measure the number and rate of reversals of accelerator travel, steering wheel travel, and brake applications. In evolving to the current HSR system, the inertial measurements of car trajectory have been dropped. In some versions of the current HSR Center, two physiological measurements have been added. By use of gold plated electrodes on the steering wheel, measurements can be made of heart rate (HR), and galvanic skin response. Actually, the current system varies but little from the original concept developed some 25 years ago. Basically, the HSR system measures the "twitchiness" of drivers rather than the actual performance in terms of vehicle motion and trajectory. The various measurements of driver control motions are computed and compared on several time bases, and the concept of total running time for traversing a given route is also used. No theoretical or model justification has been shown for the choice and utilization of the measurements obtained by the HSR system. The basis for justification appears to be that the chosen parameters were easy to measure and that the proponents of the system feel that they have *ex post facto* justification for the system in that their results appear to show some capability to discriminate among classes of drivers divided according to experience, accident, and violation history.

Reported results using the Drivometer and HSR approach have indicated a fairly high level of confidence in the method's ability to discriminate or identify beginning drivers, high violation, and high accident drivers. In addition to the work of Greenshields and Platt, several graduate thesis projects have involved use of the HSR system to classify drivers [Refs. 2,3]. The published results do not state clearly the exact means used for selecting subjects for test with the HSR system. Furthermore, the published results do not state what steps were taken to prevent bias of the results of the measurement through subjective interpretation or foreknowledge of the characteristics of the drivers being tested. Although rationalizations are given for the choice of various groups of drivers in the reported task, it seems likely that ease of availability was a major consideration in the choice of the drivers (e.g., Ford Motor Company employees, or university students.)

What appears to be lacking in the case of the HSR system (in addition to lack of a justification of the fundamental approach) is a long-term effort involving a large sample of drivers retested after a significant time interval. Although certain test results from the HSR system experiments are claimed to be predictive, they are in fact merely shown to be discriminative. In other words, the results, if accepted at face value, indicate that the method can identify classes of drivers, but there is no justification for claiming that it can predict the future behavior of drivers. Since other researchers have shown that it is currently very difficult or impossible to predict the future safety record of drivers based solely on accidents or violations, it seems unwarranted to use the term "predictive" for the HSR system results. This is not to say that use of the equipment and methodology might not furnish a predictive characterization of drivers, but rather that the results in the literature do not indicate that such a potential has been proven.

The published results of the experiments with the HSR system and its predecessors are rather voluminous; however, the volume of the literature is somewhat misleading since much of it is repetitious. A relatively limited number of experiments has been reported and reevaluated in a number of different publications. Several of the criticisms of the HSR system mentioned above and others discussed later have been touched on in a report by Spindletop Research [Ref. 4]. Much of the published material concerning the HSR system is quite self-serving and devotes considerable space to selling the concept and equipment involved. The literature does not indicate that either the concepts or the equipment have been subjected to intensive critical evaluation, either by the experimenters or others.

With the exception of the HSR and Drivometer vehicle results, there is very little in the American literature on other types of instrumented cars for driver evaluation. There have been other instrumentations made for rather limited measurements. Some of the equipment was intended to measure physiological variables such as driver reaction time and driver motor capabilities. In general, however, physiological variables have yielded low correlations with the accident or violation history of the driver. The instrumented car programs (other than the HSR type) have tended to be rather short-lived due to scientific or public apathy (lack of funds).

In the Netherlands, an instrumented car system, with the acronym ICARUS, has been developed [Ref. 5]. While the HSR system deals only with the car-driver interface, the ICARUS system deals also with the car-road interface. The ICARUS vehicle is a more general purpose experimental vehicle intended to accommodate changes in the experimental requirements. The car-driver interface can be monitored by recording movements of the steering wheel and operations of the various controls, such as brakes, horn, clutch, and turn indicators. The designers state that no permanent provisions have been made for signals from hand and foot controls because the information varies too much from experiment to experiment. The road-car interface is monitored by measuring the car's lateral position in its lane, vertical and lateral accelerations of the car body, total distance traveled from origin, and velocity. Distance or velocity information is combined with a clock signal to provide information on forward acceleration. In addition, the ICARUS system contains equipment for recording driver eye and head movements, and the driver's center of attention image on video tape. Obtaining the data on the driver's visual actions requires the use of a special instrumented helmet. In contrast to the HSR system, the data taken with the ICARUS vehicle are analog. The nature of the transducers and sensors in the ICARUS system is such that measurements can include directional sense and actual magnitude of changes rather than simple indications of change as with the HSR system. The analog signals are later digitalized for recording purposes.

The ICARUS approach appears to treat the car, driver, and road together as a system, while the HSR approach studies only the driver's activities without regard to the results of these activities other than the covering of distance. Detailed results with the ICARUS system have not been located in the literature to date, so it is not possible at this time to give correlations or estimates of the validity of the tests in evaluating driver performance.

Certain general observations have been made concerning the use of instruments for driver testing. The validity of published results is questionable because of the two classic highway safety bugaboos:

a) Lack of understanding of the overall driving task and relationships of component tasks to accident causes.

b) Not comparing driver groups on a basis of equivalent exposure (time or mileage) to external risks. The effects of externals such as traffic and road conditions cannot logically be excluded from consideration unless comparisons are made under exactly identical conditions.

III. DISCUSSION CONCERNING INSTRUMENTATION FOR THE TEST CAR BEING OBTAINED BY THE NORTH CAROLINA DEPARTMENT OF MOTOR VEHICLES

A. Description of the Present System

The purpose of this portion of the report is to evaluate the instrumentation only from an engineering and technical standpoint without passing judgment on possible shortcomings and abilities to actually evaluate driver behavior.

The Highway Systems Research unit, made by Chesapeake Systems, consists of a small data acquisition system which conditions the signal from various pickups placed around the car and records them on magnetic tape. The sensors are generally of the on-off variety, sensing such items as steering wheel motion reversals, brake applications, accelerator reversals, elapsed time, mileage, etc. The only analog type data sensed are the physiological variables. The GSR and HR signals are conditioned and digitalized for recording. Signal conditioners clean up the output from the various sensors. The recorder interface registers total number of events from each sensor and places them on magnetic tape.

B. System Evaluation

The data acquisition system is rather simple. The acquired information is reduced to a series of counts and stored on tape. The manufacturer's manual, which we presently have, and the published articles are vague as to the exact techniques used. Because of this it is difficult to evaluate the exact method of processing and storing the data on the vehicle. Some contradictory terms are used in describing some of the equipment in the various published information. The tape unit is referred to as a seven-channel recorder with a 20-channel multiplex. The illustrations of the equipment in some publications show a sign reading "six-channel recorder." The term "channel" is actually misleading; in fact, the digital recorder is a seven-track recorder, recording seven-track characters consisting of six bits of data and a parity bit. The multiplexing is apparently obtained simply through formatting of the information in the proper sequence on the tape.

Information on the sampling frequency of the tape unit is not clearly stated in the published material. In some of the publications, and on a sample program printout, data is shown in six-second blocks. If the sampling interval is six seconds, or even as fast as one second, the system will not be too useful for judging speed changes during maneuvers such as accelerating, decelerating, turning corners, emergency stops, etc.

Another possible handicap of the system is its inability to make measurements of quantity or degree, rather than number of events. For example, the number of times the brakes are applied is counted, but the actual deceleration or resulting changes in speed are not indicated (the deceleration cannot be calculated from the car speed and clock pulses if the sampling rate is too slow).

The system measures fine steering reversals on the basis of two-degree changes in wheel position. Gross steering reversals are defined and indicated as being greater than 12 degrees of steering wheel motion. It must be pointed out that these numbers do not necessarily correlate with the motion of the vehicle on the road. Steering wheels with power steering have diameters from 13 to 18 inches. With a 14-inch steering wheel, moving the wheel through an arc of two degrees is equivalent to a rim travel of less than 1/4 inch. A change of 12 degrees is equivalent to a rim travel of slightly less than 1-1/2 inches. Depending upon the vehicle conditions, the speed, and the road conditions, these changes may produce little or no effect on the course traveled by the car. The two-degree change may indicate strictly driver motions without any effect being produced on the vehicle travel. Just as an excessive number of small motions of the steering wheel does not indicate an erratic path of the car, conversely an erratic course of the vehicle may not indicate excessive motions of the steering wheel. Poor vehicle condition, uneven road surfaces, or excessive tolerance of errors by the driver may cause the car to approach, or even cross, pavement lane markings with a dangerous degree and frequency without an excessively high or low number of steering wheel motions being made by the driver.

It appears possible to obtain heart rate with an electrode arrangement such as is used in the HSR unit. However, special signal conditioning circuitry is necessary to discriminate the cardiac impulse from artifacts and under the varying input conditions caused by changes in hand pressure on the steering wheel electrodes. The ability of the unit to reproducibly measure galvanic skin response seems more questionable. It will be necessary to examine more closely the actual circuitry of the unit in order to determine if the circuits used actually provide adequate discrimination of the cardiac pulses. Some checking will be in order to determine the reliability of the unit in measuring heart rate and GSR.

IV. SUGGESTIONS CONCERNING POSSIBLE MODIFICATIONS AND ADDITIONS TO THE HSR UNIT INSTRUMENTATION

The HSR system does not appear to give adequate consideration to the car-road interface, that is, the results of the car-driver interactions. If it is presumed that the HSR measurements concerning the car-driver interface are valid, it appears that certain other measurements are required to actually indicate <u>which</u> of the car-driver interactions result in hazardous situations in the relationships between the driver's vehicle, the road, and other vehicles. In addition, pursuing the logic of the HSR instrumentation, one should be able to gain additional useful information by the manner in which a driver reacts to a particular situation. For example, the aggressiveness or risk-taking tendencies of a driver may show up in the manner in which the driver accelerates and decelerates during maneuvers. By using a frequent enough time sampling rate of the vehicle's speed, accelerations could theoretically be computed from the HSR output without resorting to transducers or accelerometers. Sampling the vehicle's speed with a frequency of four-per-second or greater should give information adequate for computation of acceleration and deceleration during maneuvers. The output of the HSR does not currently provide a direct speed measuring capability, but computes speed from odometer readings. To obtain acceleration directly from speed measurements would require the addition of an electrical generator or frequency transducer coupled to the vehicle's speedometer drive. Such a unit could probably indicate speed to an accuracy of two or three percent. As an alternative to direct speed measurement, distance measurements could be sampled in smaller increments at a greater time frequency. To obtain reasonable accuracy, distance measurements should be in increments of the order of one-one thousandth of a mile with time sampling rates of four-per-second or greater. It does not appear that the required accuracy of distance measurements can be obtained with conventional speedometer or odometer attachments. Even with the fifth wheel measuring device, attainment of the required accuracy is questionable. It would thus appear that some type of inertial measurements would be best for determining acceleration. Speed measurement for other purposes can be satisfactorily obtained through the normal speedometer type transducer or with a time base generator and the odometer readings.

It would be informative to determine whether driver characteristics are better described by actual changes in the vehicle motion, such as acceleration, speed, and road position than by an examination of the frequency with which the driver manipulates control. The use of acceleration and speed data would permit greater insight into how the driver achieves his running time for a particular course. It could be determined if a driver's running time is determined by his reactions to traffic and maneuver situations or whether it is governed by his free road speed. If acceleration measuring devices are installed on the car, there is no necessity for making quantitative measurement of such items as force applied to the brake pedal or the amount of change made in the accelerator position.

Measurement of the variables previously mentioned would involve analog data. Analog to digital conversion would be required to get the data in a form suitable for recording on the HSR recorder since the HSR system currently completely avoids analog type data. This does have the advantage of saving in the amount of tape required for recording and simplifying the required electronics. As has been pointed out in a review by Spindletop Research [Ref. 4], the HSR instrumentation is quite simple--perhaps even naive. However, simplicity, *per se*, is not necessarily a criticism. In fact, simplicity of equipment is highly desirable if the simplicity still permits measurements of the actual critical factors with satisfactory accuracy. Thus, again the question resolves itself to one of whether the variables chosen to be measured are indeed significant.

In order to quantitatively measure some of the vehicle-road relationships, instrumentation can be provided in a manner similar to other experimental vehicles. Instruments can be used to determine the test car's relationship to lane delineation markings, or to some special detector or reference marking which are part of the roadway. If the roadway or lane delineations are clearly marked for visual perception, it would be relatively simple to provide photoelectric detection of the vehicle's position with respect to these markings. Using differential type techniques comparing the reflectivity of the regular road surface with that of a marking, and other techniques for signal conditioning or special discrimination against false reflections, it should be possible to accurately determine when a vehicle approaches or crosses a lane marking or when it crosses other reference markings on the pavement. If the test vehicle is to be used on a special test track, it would be possible to provide a special marking, perhaps down the lane center, to very accurately determine the vehicle's tracking on the course. Such a special marking could be made relatively inconspicuous to the human eye, but still readily detectable by a photoelectric or other type instrument.

A possibility for additional instrumentation that has been given frequent consideration is the use of some device to determine the position of the driver's eye focus. Devices are available which indicate center of the driver's visual field. However, all such devices currently require special helmets or attachments to the driver's head. Considerable time is required to become accustomed to such a device. The distraction caused by such a device would seriously jeopardize results of such equipment for routine driver screening. At present, such devices appear useful only for research type experiments, utilizing well-accustomed drivers. It may be possible to use a much simpler type device to determine when the driver's vision focus passes over a certain point, such as the rear view mirror of the car. A device fixed on the rear view mirror could measure the frequency or duration of the driver's use of the rear view mirror; however, development of any vision monitoring device could in itself involve extensive R&D effort.

Although published material concerning the HSR has indicated that normal traffic and road conditions have little to do with the measured actions of good drivers, the point still seems quite open to debate. In order to fully evaluate the effect of traffic and road conditions, it is necessary to follow one of three courses. One means is to have an observer ride with the driver being tested; the observer records significant events in traffic and road conditions. Another possibility is to have photographic equipment or video tape recording equipment on board the car to make records of the conditions. This has the advantage of removing possible influence of the observer on the driver's performance. However, the recorded visual information must be examined by an observer at a later time. This still involves a real-time situation where the observer is required to spend as much time with the record as the driver did taking the test. The observer time requirements could be reduced somewhat by viewing the recorded information at a greater than normal speed or by having information recorded in a single frame mode, that is, essentially a sampling type mode at regular intervals. Even with these devices, the observer time could probably not be reduced below one-third or one-fourth the real-time of the driving test. For routine testing purposes, the amount of manpower required for observer analysis could become prohibitive. The third alternative for determining the influence of road and traffic factors is to have the test run on a special course with reproducible, controlled conditions. These conditions would not have to be the same for every driver, but they would be known. For example, a simulated intersection on the track could be equipped with a traffic signal. It would not be necessary to have an observer in the car in order to determine the driver's response to various situations involving the traffic signal (for example, a yellow light as he enters the intersections, or an excessively fast signal change). Other situations could be staged or simulated where the driver would be required to make decisions and take actions. If some particular weakness is suspected in the driver's capabilities or attitudes, the proper situations could be arranged to test for this. These considerations should be strongly considered in the current planning for the Highway Safety Research Center's use of a testing track.

Another approach which appears worthy of consideration is the development of an instrumentation package which could be attached to any vehicle with ease and without distraction of the driver. Such a unit might consist of an instrument package sitting in the trunk of the car and a fifth wheel device attached to the rear bumper. Such equipment would permit testing drivers in their own cars or vehicles with which they are thoroughly familiar. Computer analysis of the resulting data could compare the individual driver's performance with norms for good drivers in the same type of vehicle. Such a system would have the advantage of permitting testing for special purpose licenses or vehicle class licenses, if the proper reference data has been provided in the computer analysis program. Consideration should be given to comparing the cost effectiveness of the use of such instrumentation equipment to the use of instrumented, state-owned vehicles for driver testing.

V. RECOMMENDATIONS CONCERNING A TEST PLAN FOR THE USE OF THE HSR INSTRUMENTED CAR

Six major topics need to be covered in the plan for bringing the instrumented car concept to the point of being a useful device for routine driver screening or special driver re-examination. With the HSR unit being purchased, the first step should be a test of the system reliability, disregarding questions concerning the validity of the concepts involved. The unit should be tested for reproducibility, accuracy, and consistency in recording data on the variables which the system purports to monitor.

Once the engineering soundness of the HSR unit has been established, the validity of the basic concepts and types of measurements made for discriminating and predicting driver performance must be established. This will involve considerable time and effort. Various categories of drivers must be tested. Extreme care should be exercised in choosing the drivers to be tested. When classifying the drivers to be tested, it is particularly important that the driver's exposure history be considered in evaluating him as a good or poor driver in terms of accidents or violations. The numbers of each class of driver should be as large as possible to gain a broad, statistical base for the measurements. Sound experimental design will be required to insure statistical validity of the results. In addition, it is highly desirable that follow-up testing be done with as many of the drivers as possible. Thus, after a lapse of six months to a year, and perhaps at other intervening time intervals, drivers should be rechecked to determine the variation of their performance with time and the ability of the testing methods to predict driver behavior. It must be understood that the approach being used is almost entirely empirical until some fundamental information is available concerning the actual nature of the driving task and the driver decisions involved.

During the preliminary testing of the concepts involved in the HSR instrumented car, decisions should be made concerning the need for additional instrumentation. This instrumentation should be adapted to the car as quickly as possible so that its usefulness may be validated with the same testing program as the original HSR unit. Although some portions of the instrumentation and testing program will necessarily be evolutionary, it is desirable to fix as many of the instruments and variables to be measured as early as possible in the program. As the data base is developed and analyzed concerning the usefulness of the instrumented car concepts, consideration should be given to applying these concepts on specially equipped tracks or test courses. The required equipment and methods for use of the car in a combination with the special track should be developed.

As has been pointed out earlier, proper selection of driver samples is essential to obtain valid data. Sound statistical design and analysis is needed to rigorously justify the instrumental car approach to driver testing. The detailed statistical methodology to be used will be included in the final report and plan resulting from this contract.

When the various concepts involved in the instrumented car and its method of application have been developed, consideration should be given to the feasibility of developing a special package which can be attached to ordinary vehicles. Consideration should also be given to the possibility of having instruments applicable to special classes of vehicles, such as cars, busses, trucks, etc. The cost-effectiveness of such instrument packages as compared to the use of a large number of specially equipped vehicles (with some of each class) should be considered.

Finally, when and if the concepts of the instrumented car, with or without the use of a special test track, have been validated, planning should then be done to provide a test program suitable for routine application in the screening or examination of drivers. This, of course, is the ultimate aim of the entire program. It must be realized, however, that attainment of this goal will neither be quick nor easy. Certainly this goal will not be reached within a few months, or perhaps even a few years. Some additional details of the plan for the testing of the instrumented car to determine its usefulness as a driver screening vehicle are given in the following outline.

VI. TEST PLAN OUTLINE FOR INSTRUMENTED CAR FOR DRIVER TESTING

A. Validation Test of HSR Vehicle Instrumentation

1. Reproducibility and Reliability

    a) Test controls for reliability of output signals, noise, errors, (mechanical cycling of controls preferable).

    b) Test reliability and discrimination ability of signals from steering wheel electrodes. Check for errors in signals, noise, effects of hand pressure, position, moisture and motion. If possible, compare ECG with body electrodes.

        1) Stationary tests.

        2) Actual driving tests.

    c) Test reliability of recording equipment.

    d) Engineering evaluation of equipment and its potential for recording other data, including quantitative measurements.

    NOTE: During tests a) and b) above, project members will be driving the HSR vehicle, becoming accustomed to it.

2. Sensitivity and Relationship of Vehicle Response to Control Changes as Monitored

    [Run tests at different speeds (possibly 15 or 25, 45 and 60 mph.).]

    a) Check effects of the measured 2° and 12° changes in steering wheel position on vehicle travel. Estimate angular changes which realistically correspond to changes in vehicle travel on straight, curving, smooth and rough roads for maintenance of tracking and for maneuvers (such as passing).

b) Check effects of measured changes in throttle position as monitored by HSR instruments. Estimate realistic changes in throttle position for significant changes in vehicle speed under varying speed, acceleration, load and road conditions as described immediately above.

c) By <u>external</u> observation, estimate quality of driver/vehicle tracking on road and compare with output of HSR monitors (check for correlations of actual vehicle performance compared with what HSR record indicates as driver performance).

d) Compare measures of HSR vehicle response in a)-c) above with estimates for other makes and ages of vehicles.

3. Analysis

a) Analyze test results.

b) Determine if additional instrumentation is necessary to indicate factors of driver behavior or vehicle response.

c) Determine need for external instrumentation, observation or assisting devices (such as special road markings or fixtures).

B. <u>Changes or Additions to HSR Instrumentation (as Indicated by A.3.)</u>

1. Design, Build, Check and Install Additional Instrumentation

2. Modify HSR System

3. Plan and Make Provisions for External Aids (as Indicated by A.3.c.)

4. Retest Instrumentation System According to Part A.

C. <u>Obtain Baselines for Validation of Approach and Concepts for Driver Testing</u>

1. Establish Guidelines for Testing Program

a) Using sample of inexperienced and experienced drivers, evaluate the adaptation time required for using the HSR car reproducibly.

b) Determine time (after adaptation) required to obtain reproducible results in a driving test.

c) Using same sample, determine reproducibility of results under varying road and traffic conditions. Also compare road course and track results (if possible).

d) Determine variations in performance of individual drivers with physiological variables (tired, slight illness, etc.) and time of day.

e) Evaluate results and use in detail plan for testing with larger groups. Plan to include:

   1) adaptation time permitted,

   2) length of total test,

   3) conditions justifying inclusion, exclusion, or postponement of tests for individual drivers,

   4) road and/or traffic conditions for tests.

2. Selection of Driver Samples

   a) Set size of sample groups according to statistically planned procedures.

   b) Select samples from following classes.

      1) New license applicants (no previous license of any kind).

         a) Drivers passing present road test.

         b) Drivers failing present road test.

      2) Good drivers (low violations, low accident rate) experienced.

         a) High exposure/and

b) Low exposure/or

c) Group all of equivalent exposure class.

3) High violation drivers.

a) High accident,

b) Low accident,

c) High exposure/and

d) Low exposure/or

e) Group all of equivalent exposure class.

4) High accident drivers.

a) High violation,

b) Low violation,

c) High exposure/and

d) Low exposure/or

e) Group all of equivalent exposure class.

NOTE: As an alternative to the various sub-groups above, large samples could be used and discriminate analysis employed to classify drivers. Results of discriminate technique on random sample would probably show more overlap of comparisons than sub-groups selected to extreme classification standards.

3. Testing of Driver Groups

a) Test drivers from each subclass.

b) Run analyses of test results.

c) Compare test results with driver category on basis of both learning curve and accomodated data.

d) Retest drivers after one or more time intervals (6 months or more).

e) Compare retest and original results. Examine predictive success of original tests with new drivers. Compare with evaluations based on present testing.

4. Summarize Test Results

Determine if concepts are proven sufficiently to warrant wider use.

D. <u>Develop Standardized Testing Routine for Licensing and Relicensing</u>

E. <u>Extension of Instrumented Testing Concept</u>

1. Examine Feasibility of

a) Test instrument package attachable to different vehicles (fifth wheel and inertial detectors).

b) Instrumentation of different types of vehicles for class or limited licensing (trucks, buses, handicapped drivers).

c) If feasible, develop attachable or special vehicle instrumentation.

d) Validate equipment as in A.-C. above.

e) Set standards and methods for routine testing.

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APPENDIX B

TEST PLAN FOR CHECKING INSTRUMENTATION IN HSR CARS*

*Prepared by Dr. A. R. Schleicher, Research Triangle Institute Operations Research and Economics Division, and submitted to Highway Safety Research Center on August 5, 1970.

I. DISCUSSION OF ERROR SOURCES

The instrumentation of the HSR car is of two types -- the physiological measuring and the driver action measuring. From the literature, it appears doubtful that the physiological (galvanic skin response and heart rate) measurements are either reliable or significant. The variety of combinations of possible uncontrolled stimuli and individual responses is such that extensive research appears needed to justify the use of physiological variables. This problem, combined with basic questions concerning the ability to make the necessary measurements with unattached electrodes, suggests that postponement of investigation of the physiological factors is in order.

The driver action measurements all involve four basic steps on the vehicles. These steps are counting, sampling, timing, and recording. All other processes and manipulations involving the data are accomplished in the computer processing. Therefore, it is necessary to evaluate the accuracy and reliability of the four basic steps on the vehicle. It is possible to test several of these steps in the same procedure. The possible sources of errors are listed here for each of the four basic steps.

a. Sources of Counting Errors

(1) Switch reliability (for mileage, accelerator reversals, accelerator depressed time);

(2) Mechanical linkage problems;

a) Brake light switch function (for brake applications counts);

b) Slippage of friction linkage on accelerator (for accelerator reversal counts);

c) Slippage of friction drive on steering wheel hub (for steering reversal counts);

(3) Speedometer pickup errors

b. Sources of Errors in Sampling

(1) "Channel" multiplexing circuitry for recorder;

(2) Time base accuracy of recorder.

c. Sources of Errors in Timing

(1) Errors in elapsed time clocks in car (for running and total time);

(2) Deviation of recorder framing rate from nominal;

(3) Lack of correspondence between "accelerator depressed" time and true running time.

d. Sources of Errors in Recording

(1) Recorder reliability (includes item c (2) above);

(2) Tape printing;

(3) Computer tape reading;

(5) Noise and false signals to recorder input.

II. PROGRAM OF TESTS FOR ERRORS IN INSTRUMENTATION

It is suggested that the following test procedures be applied to each of the three HSR cars purchased by the State. Particular attention should be given to variations between cars.

Timing accuracy is very basic and easily checked. Therefore, it is recommended that timing be verified first. The elapsed time and running time clocks may be checked against manual stopwatches of known accuracy as follows.

A. Tests for Timing Errors

1. Total trip time and running time

a. With engine running at idle, no accelerator application, check total time counter against stopwatch for one minute and five minute intervals. Repeat 10 times. Check to see that running time counter does not change.

b. Repeat tests with air conditioning operating at full capacity and headlights on bright (to check for variations with battery and alternator load).

c. Repeat above tests for trip time (without air conditioner and headlights) with accelerator partially depressed (at engine speeds of approximately 1500 and 2500 rpm). A tachometer or mechanical stop on accelerator should be used to reproduce speed fairly closely). Note also whether any reading is obtained on running time counter, vary accelerator position to determine engine speed at which timer begins to indicate.

d. Repeat tests from (a) above with car being driven, stopping and starting. If previous tests have shown no effect on timing due to engine speed or electrical load, air conditioning and accessories may be used as desired. By using two stopwatches, running time and trip time may be checked simultaneously. Driver may assist by switching on and off the HSR timers on signal from observer who is using stopwatches.

e. By trial and error, determine as accurately as possible the vehicle speed at which the running time counter begins to function.

2. Recorder framing rate check

The best way to check recorder framing rate is to take off signals from the recorder driving motor or clutch circuits. The tape advance pulses can be measured with a calibrated oscilloscope, electronic counter/timer or frequency meter. (It is presumed that the accuracy of such equipment will be known.) The actual framing rate of the recorder will then be known. The framing rate should be accurate for a quality recorder and be independent of variations in supply power with car engine speed or load. If the framing rate is found to vary, enough checks should be run to permit the error and standard deviation to be estimated. Any subsequent calculations involving the framing rate as a time base should be corrected if a serious error is found. It is unlikely that framing rate errors will be a problem in comparing drivers with a single car, but serious errors could cause poor correlation of results between different test units.

B. Counting Errors

Counting errors may be due to several problems as previously listed. Assuming that quality components have been used in the instrumentation, commercial switches should provide reliability far greater than that of the mountings and mechanical linkages in an add-on type system like the HSR package. The mechanical components may be checked as follows:

1) The brake application indicator/counter should be checked with the car in motion. Test to see if the minimum pedal pressure required to produce detectable braking will register on the counter. This will require some "seat of the pants" feel and judgment by the driver. The number of tests required depends on the confidence of the driver in his feel of the braking action. It would be desirable to try tests with two or more drivers. If the brake application counter does not register with minimum braking, the stop light switching must be adjusted or replaced for greater sensitivity.

2) The friction linkage on the accelerator reversal pickup can be tested with the car either parked or in motion. With the car parked, the operator may record his own results. With the car in motion, an observer or recording equipment will be needed. The testing is simply a comparison of a careful manual count of accelerator reversals with the mechanically recorded count. This should be done on a test track to allow the necessary concentration of drivers and operators. The operation of the accelerator reversal switch should be checked over a range of throttle positions. Twenty-five to fifty cycles at each throttle range should be made. If no count failures or extraneous counts are noted, testing may be discontinued for this item on the particular car. If counting errors are noted, additional tests should be run until the error level may be estimated.

During tests of the accelerator reversal counter, observers should note whether the amount of accelerator change required to produce a count causes an appreciable change in vehicle speed at the different throttle ranges.

3) The friction drive of the steering reversal detector is a likely spot for failure. Because of the emphasis put on steering reversals in previous published work, this device should be closely checked before using data from it. The sensitivity of the pickup used is such that manual count camparisons would be difficult. Drivers or observers could not accurately detect the small motions involved at the frequency of natural occurrence. It is recommended that a mechanical cycling device be used to move the steering wheel. A constant speed drive can be used with a crank linkage attached to the steering wheel rim. The crank linkage should provide about a two-inch stroke (motion of wheel rim) to give both large and small reversal counts at each stroke. The counts from the HSR unit are to be compared with the known number of strokes of the drive mechanism over a given time period. A number of tests of at least several hundred strokes each should be done initially. The stroke rate should be about 25 per minute. It would also be desirable to run additional checks at a stroke rate of 75-100 per minute to check for detector drive slippage at high rates. If no deviations in counting are found after the initial few hundred strokes, the testing may be discontinued. If errors are found, the testing should be continued long enough to estimate the limits and standard deviations for the counts.

It should be pointed out that both the accelerator reversal and steering reversal detectors involve friction drives which are sensitive to oil, grease and other contaminants and wear or aging of friction surface which may reduce reliability with time. The problems due to friction drives could be overcome by using positive mechanical coupling and electrical motion detection rather than switches. The motion of a positively coupled, toothed metal piece could be detected by electromagnetic or optical means with much less age and environmental sensitivity.

4) Speedometer pickup accuracy should be checked on a test track. The basic car speedometer and odometer should be checked with a fifth wheel instrument. The sensitivity of the speed change detector should be determined by careful acceleration and deceleration over the range of legal speeds. An observer will be required to accompany the driver.

There should be little problem with the durability of this detector. The chief questions to be settled are sensitivity of the detector and correlation with accelerator motions. A special problem that may occur with a unit of this type is due to insufficient damping in the spring loaded indicator wheel. If damping is insufficient, irregularities in motion of the flexible drive cable (from the transmission) may cause false signals. This is best checked by raising the rear wheels of the car off the ground and running the engine in gear at a constant speed. The engine should be held at a constant speed for 30 seconds to one minute. This may be accomplished by mechanically locking the accelerator in the desired position. (The cold idle cam may be satisfactory for this.) Checks should be made at several indicated speeds up to 60 mph. While the throttle (speed) is held constant, no speed change counts should be generated. If counts are made, it indicates insufficient damping in the sensor or binding or excessive loading of speedometer drive cable. The presence of error counts indicates that adjustment of the unit may be required.

C. Checking of Electronic Reliability of Recorder and Interface Equipment

Checking the reliability of the multiplexing circuitry and the other recording electronics would be a tedious job. Such checking would best be done in an electronics lab. In view of the gross nature of the other portions of the equipment and the data being taken, it does not seem worthwhile to pursue this area unless definite symptoms of difficulty are noted.

D. Correlation of Driver Action Counts With Vehicle Motions

Although it is beyond the scope of this report, it seems in order to briefly examine the correlation between vehicle motions and the measured driver actions. If the instrumentation counts driver actions so small that no effect on the vehicle results, then the measurements are indicators of driver nervous actions rather than driving performance. It is possible that a correlation exists between drivers' nervous actions and driving performance. If this is all that is being shown by the HSR instruments, other measurement approaches may be more useful and straightforward. Microphonic or capacitively coupled sensors could be used to detect small movements of the driver's body. Such equipment need not be elaborately integrated into special vehicles, but could be placed in desired cars with relative ease and speed.

Correlation of accelerator and braking actions with vehicle speed changes has already been discussed. The significant point remaining is the relation of measured steering rèversals to vehicle tracking.

1. Tests should be run at least at three different speeds spaced over the range 15-60 mph. An observer riding in the car should estimate the changes in direction produced by the minimum steering wheel motions which produce counts for small and large steering reversals. This should be done on a smooth, straight road or track.
2. In addition, tests should be made to allow the observer to estimate required angular changes of the steering wheel which realistically correspond to changes in vehicle travel on smooth, rough, straight and curving roads for maintenance of tracking and maneuvers (turning, passing, etc.) To facilitate this, some sort of pointer and angular scale arrangement can be mounted on the steering wheel column.
3. It would also be desirable to use an external observer to determine if the minimum counted steering, accelerator and braking actions produce noticeable variations in vehicle motion or road performance. Such external observation could be done in conjunction with previously described related test steps.
4. To gain an idea of the applicability of HSR measurements to driver actions in their own cars, comparison steering tests should also be made with different makes and ages of cars. Steps 2 and 3 immediately above can be repeated on the different cars.

APPENDIX C

TEST PROGRAM FOR NORTH CAROLINA HIGHWAY SAFETY RESEARCH CENTER'S INSTRUMENTED VEHICLES*

*Prepared by Dr. A. R. Schleicher, Research Triangle Institute, Operations and Economics Division, and submitted to the Highway Safety Research Center on April 13, 1971.

I. Objectives (Long Range and Near Term)

One of the primary objectives of the instrumented vehicle research program at the Highway Safety Research Center is to determine the feasibility of using such a vehicle in the driver licensing program as a tool for screening out drivers with poor or unacceptable driving characteristics or skills. Theoretically, an instrumented vehicle could replace the current road test in driver licensing in that it would provide an objective measure of driving capability. This, however, is a long range objective of a program which will require much basic research in defining what constitutes "poor or unacceptable" driving performance, along with extensive testing and evaluation.

It is unrealistic to formulate a complete and detailed test plan which is rigid in form to accomplish the above-mentioned objective in such a complex program. The course of action at some phase of the study is highly dependent upon what has been determined from the program up to that point in time. Hence, the primary purpose of this report is to outline a test plan covering the initial phase of the overall study. Included in the report are: (1) recommended driver categories for initial test and evaluation, (2) number and selection of drivers and (3) data analysis procedures.

II. Test Plan Assumptions

It should be emphasized that the procedures discussed in this report are based on the assumptions that data provided by the instrumented vehicles are reliable or, if not, the magnitude of instrument measurement errors and/or bias is known. It is also assumed that a test course will be available for use in conducting all driving tests. Details of the test course, its size, shape, location and degree of complexity (road condition, traffic conditions, hazards, etc.) are unknown at this time. These missing elements of information have a direct impact on the sensitivity of any evaluation plan. This is especially true with regard to the number of drivers required for testing, since differences in the measured responses between groups of drivers should be related to test course complexity.

III. Driver Categories for Initial Test and Evaluation

If it were possible to define, explicitly, the set of conditions which characterize a "poor" driver, then a test procedure could easily be developed for determining whether the instrumented vehicle could be used to discriminate between the "poor" and "not-poor" (i.e., acceptable) driver based on the measured driver responses.

The real problem, however, is in defining the set of conditions which satisfactorily describe a "poor" driver. Applying Webster's definition of the word "poor" to drivers is of no help. In previous investigations [1, 2, and 3], which employed the Drivometer as a measure of driving skill, attention was directed toward discriminating between groups of drivers characterized, for example, as high accident drivers, high violation drivers, low accident drivers, beginning drivers, and so on. The results of these investigations look promising with regard to classifying a driver into one of these classes according to his overall driving response. However, the problem remains as to how these results may be translated into "poor" driver characteristics. This is recognized as a problem but little effort has been directed toward its solution. "Poor" is a relative term which has little or no meaning unless quantified. This area will require extensive research if the long range objective is to be achieved.

Test and evaluation of certain driver groups can and should be conducted at the same time a definition of a "poor" driver is being developed. There are two reasons for this: first, the results can be very beneficial in deriving a satisfactory definition, and secondly, to determine if the driver responses measured by the instrumented vehicle show some promise or potential in discriminating between groups which are considered to have widely divergent driving patterns.

It is suggested that four driver groups or categories be considered for initial testing and evaluation. These are:

Group I - Experienced drivers whose driving record shows no accidents and no violations. Included in this group of drivers are those whose vocation demands a heavy amount of driving. For example, driver training instructors, truck (taxi) drivers, salesmen, patrolmen and so on. Cost should be considered in the decision as to which group of test drivers are to be selected. The Department of Motor Vehicle's file will provide a check as to the clean driving record of the selected drivers. To obtain experienced drivers, a lower limit on age, say, 30-35 could be used.

Group II - Experienced drivers whose driving record shows the highest accumulation of points, over, say, a five-year period. Assuming a list of drivers ranked in ascending order according to the number of accumulated points over a five-year period could be obtained (Department of Motor Vehicles), then drivers could be selected, starting at the top of the list and working down. It would seem advisable to discount points accumulated as a result of alcohol usage since the driver would be tested while sober. To obtain experienced drivers, a lower limit on age, say, 30-35 could be used.

Group III - Inexperienced drivers. Test drivers for this group could be selected at the driver licensing stations from those persons obtaining license for the first time.

Group IV - Intoxicated drivers who otherwise meet all Group I requirements. The recommended level of alcohol under which drivers are tested is .10%. Of course, only volunteer drivers meeting the requirements of Group I could be used. This group represents an artificially constructed population of drivers which may be referred to as "poor" drivers. This will be discussed in more detail later in the report. If possible, the same drivers selected for Group I should be used.

Groups I, II and III may be recognized because of their similarity to driver groups included in some previous investigations found in the literature ([1, 2, and 3]). Groups I and II are included because they may well represent the two extremes - Group I as "good" drivers and Group II as "poor" drivers. Quotes are used to indicate these terms as relative descriptors. The inclusion of Group III permits an evaluation of the instrumented vehicle's ability to discriminate between two groups of drivers (Groups II and III) whose response patterns may be quite similar for certain parameters.

The problem of defining a "poor" driver has already been mentioned. This problem can be sidestepped, at least temporarily, by manufacturing a population of drivers defined by North Carolina State law to be "unacceptable" drivers. Drivers from this manufactured population could then be tested to determine whether their response patterns differed from other driver groups. This population may be artificially produced by requiring a driver prior to testing to consume a sufficient quantity of alcohol to raise the blood alcohol level to .10%. Since this level of alcohol is recognized by law as producing conditions unacceptable for drivers then it would seem appropriate to include drivers with these conditions in the evaluation program. Some work in this area has been done by Light and Keiper [4]. Using an optical driving simulator, they tested drivers in both a non-alcohol and alcohol condition and found under the alcohol condition: a significant change in lateral control, an increase in decision-reaction time, increase in error scores on the eye-hand coordination test, larger number of attempted and completed passing maneuvers, and more accidents. The inclusion of this group, however, would increase the difficulties in the conduct of the tests, as additional controls would be required. Also, additional consideration should be given to the conditions of the test, in view of the potential hazardous situations which may arise. Under realistic test conditions, if the driver responses generated by the instrumented vehicle are not able to discriminate between Group I and Group IV drivers (with a high probability of success), then the long range objective of the research program should be re-evaluated. In order to make this determination early in the program, it is suggested that Group IV drivers be included as one of the initial test groups.

IV. Number and Selection of Test Drivers

Guidelines for the selection of test drivers within each of the initial test groups are discussed in Section III. One additional item to keep in mind during the driver selection is the economic factor. Hence, drivers in the area adjacent to the test track should receive top priority in selection.

It was indicated previously that the test track size, shape, location and complexity have a pronounced effect on the number of test drivers required to discriminate between group driver responses. Other factors to be considered in determining the number of drivers to include in the test are: variability in responses from driver-to-driver within a particular group, the magnitude of the true differences in responses from group-to-group, and, the magnitude of the differences in responses which, if they exist, will be detected (with some stated probability) in the experimental testing program. In view of the fact that answers to most of these considerations are unknown at this time, the following sequential type approach for testing is suggested.

Step 1. Select as a preliminary sample, 15-20 test drivers for each of the four driver categories (Groups I, II, III and IV).

Step 2. Conduct test on the preliminary sample of test drivers.

Step 3. Analyze test results to determine how many additional test drivers are needed to detect a realistic difference in driving responses. Means and variances estimated from the preliminary sample can be utilized in this decision.

Step 4. Determine final sample sizes needed (from Step 3), select drivers and conduct tests.

The recommendation to test and evaluate drivers in all four groups is made so as to provide background information covering a wide range of drivers. Also, this preliminary information can be used in deciding which groups to include in further in-depth studies. If, for some reason, all groups cannot be tested, it is recommended that initial efforts be concentrated on Groups I and IV as these logically appear to be the most divergent in driver responses.

V. Data Analysis

The instrumented vehicle provides information on, say k variables for each driver tested. We wish to determine if the multi-variable information generated through this technique can be utilized to classify (with a high degree of success) a driver as a member of one of two possible groups or populations. For example, a driver is classed as a "poor" driver or "not poor" (i.e., acceptable) driver. It is likely that some of the variables (driver responses) measured by the instrumented vehicle are more important than others in classifying a given driver; hence, these important variables should be given additional weight. Conversely, those variables which do not supply as useful information in classifying a driver should receive less weight--even to the point of being discounted entirely (i.e., zero weight).

With these objectives in mind, it is suggested that a discriminant analysis be employed. In this type of analysis, the experimental data are used to estimate the parameters of a function Z (Discriminant

Function) which has the form

$$Z = \lambda_1 X_1 + \lambda_2 X_2 + \ldots + \lambda_k X_k \qquad (1)$$

where X_1, X_2, ..., X_k are the measured variables and λ_1, λ_2, ..., λ_k are the corresponding weights.

In 1936, Fisher [5] developed procedures for estimating the λ's such that if an analysis of variance were conducted on the Z values, the ratio of the variance between groups to that within groups would be a maximum. For the case where three variables are included (i.e., X_1 = number of brake applications, X_2 = number of steering reversals, and X_3 = number of accelerator reversals), estimates of the λ's are obtained by solving the following equations:

$$\begin{aligned} \lambda_1 \Sigma(x_1^2) + \lambda_2 \Sigma(x_1 x_2) + \lambda_3 \Sigma(x_1 x_3) &= d_1 \\ \lambda_1 \Sigma(x_1 x_2) + \lambda_2 \Sigma(x_2^2) + \lambda_3 \Sigma(x_2 x_3) &= d_2 \qquad (2) \\ \lambda_1 \Sigma(x_1 x_3) + \lambda_2 \Sigma(x_2 x_3) + \lambda_3 \Sigma(x_3^2) &= d_3 \end{aligned}$$

where x_1, x_2 and x_3 represent deviations from their respective group means $\overline{X}_g$ (good drivers) and $\overline{X}_p$ (poor drivers), and $d_1 = \overline{X}_{g1} - \overline{X}_{p1}$, $d_2 = \overline{X}_{g2} - \overline{X}_{p2}$, $d_3 = \overline{X}_{g3} - \overline{X}_{p3}$. The second subscript identifies the variable number (X_1, X_2 or X_3) to which the group mean applies.

The set of equations in (2) may be solved directly for the λ's or may be expressed in terms of correlation coefficients and solved to give estimates of the λ's. Having obtained estimates of the λ's, the discriminating power of the Z function can be evaluated by an analysis of variance. The techniques which are standard in multiple regression analysis can be applied in testing hypotheses concerning the estimated λ's. A detailed discussion of the Discriminant Function along with a complete example of its application is given in [6].

For the three variable case the end result is the function

$$Z = \lambda_1 X_1 + \lambda_2 X_2 + \lambda_3 X_3. \qquad (3)$$

For each of the two groups calculate the average value of Z, that is, compute $\bar{Z}_g$ (good drivers) and $\bar{Z}_p$ (poor drivers). Next, calculate $D = (\bar{Z}_g - \bar{Z}_p)\ /2$ and use this as the point against which to compare a value of Z for a particular driver to determine which group he belongs. If $\bar{Z}_g > \bar{Z}_p$ then drivers with Z values greater than D would be classified as belonging to the group of good drivers and values of Z less than D would classify the drivers as poor. If $\bar{Z}_g < \bar{Z}_p$ the classifications would be reversed from that given in the preceding sentence.

VI. Some Additional Comments on Discrimination of Driver Responses

Driver discrimination by response requires a pattern of normal expectations and a cut off for deviant expectations. Two basic questions which must be answered are: How can a pattern of normal expectations of driver response be established and what elements are important in establishing the stimulus-response relationship which can be found through the instrumented car? The ideal driving relationship has been postulated as one in which the driver (and his passengers) travel from point to point with a minimum of effort and anxiety. The minimization of effort and anxiety cannot be done on a total trip basis because the driving effort and anxiety will not be constant over a driver examination course.

West [7] has utilized a minimum deviation approach to determine the response of a group of drivers to a given highway environment. This approach will provide a background for calibrating a driver examination course. The course can be divided into approximately 200 equal length sections which will have a response mean and variance. These response means are computed to minimize the variations on each section. The response variances are computed based on the contigous sections. This process establishes course norms. A deviation from the course norm will receive "a point." The cut-off score (i.e., the driver scores 60) can be established and will provide both an indication of his driving skill and his perception of the related environment events.

The implementation of this process requires the basic research tasks discussed in the previous sections of this report.

APPENDIX D

DRIVER'S EYE MOVEMENTS: A LITERATURE REVIEW*

*Prepared by Stanley M. Soliday, Associate Professor of Industrial Engineering, N. C. State University, and submitted to the Highway Safety Research Center on October 9, 1970.

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INTRODUCTION

This report reviews the literature pertaining to automobile drivers' eye movements. Its purpose is to discover what is known about the ways people move their eyes when they drive automobiles, and to determine, if possible, whether or not good and poor drivers' eye movement patterns differ. If patterns in the two groups are in fact different, it might be possible to train poor drivers to move their eyes in the same kind of pattern that good drivers use, and thus improve their driving. Techniques developed to train eye movements of poor drivers might be equally applicable to the novice driver, and this could conceivably have a good deal of influence on driver training programs.

The report is divided into six sections. Section I provides general information about eye movement measuring techniques and Section II discusses parameters of eye movements in search tasks (since the visual task in driving is essentially a search task.) Section III reviews briefly some studies in which eye movements have been trained by operant conditioning techniques (since these techniques might be applicable to training drivers' eye movements.) Section IV reviews studies in which drivers' eye movements were measured; Section V is a general discussion of the previous material, and Section VI consists of recommendations for further study.

I

EYE MOVEMENT MEASUREMENT

When a person looks directly at an object and his gaze fastens on that object for a short period of time, the object is said to be fixated, or the person is said to be fixating the object. When the person moves his eyes to fixate another object, the movement of the eyes as they jump from one fixation to the other is called a saccade, from an old French word referring to the flick of a sail (Gregory, 1968). Saccades can be voluntary or involuntary. They are very rapid, and their velocities may be as high as 600 degrees per second for very long excursions (Young, 1963).

The eyes move mainly by saccades (Gaarder, 1968), and it is generally agreed that when one eye makes a saccade, the other makes exactly the same kind of movement. In other words, the eyes are perfectly synchronized in their saccadic movements. Gaarder says that there are 120 to 240 saccades per minute in ordinary viewing (Gaarder, 1968). It is also believed that the eyes are fixated about 90 percent of the time, and travel from one fixation point to another in the other 10 percent (Gould, 1969).

There is one other kind of eye movement conceivably pertinent to the study of drivers' eye movements, and that is the pursuit movement. Pursuit movements are slow movements the eye makes when it tracks a slowly moving object. Pursuit movements are made at rates of 1 degree to 30 degrees per second, are involuntary, and cannot be executed in the absence of a moving object (Young, 1963).

Ways of Meauring Eye Movements (Oculography)

The description of oculographic techniques that follows was taken largely from the paper by Young referred to earlier (Young, 1969). The first method is direct observation of a subject's eyes; the observer simply watches how a subject moves his eyes to look at or follow an object. The second method uses after-images, on the principle that the images of a regularly flashing light will leave a series of after-images on the retina. The number and spacing of these after-images indicate the duration and velocity of the eye movements. Both of these subjective methods are imprecise and are used very little, if at all, to scientifically study eye movements.

Various types of mechanical transducers have been used for eye movement measurements. As an example, one investigator anaesthetized the eye of a subject and fastened a lightweight rod to the cornea with a glass bead. The other end of the rod touched a rotating drum kymograph, and thus could produce a permanent record of the subject's eye movements. Techniques like this obviously have limited usefulness.

Several investigators have made photographic records of eye movements. This technique is similar to the method of direct observation described above, but of course has the advantage of producing permanent records. A refinement of this technique in wide use today produces good data. In this refinement, a beam of light is projected onto the subject's cornea. The cornea reflects the beam onto a mirror or prism which reflects the beam again, this time to a camera that is also focused on the scene at which the subject is looking. When the camera actually takes a picture, the beam of light originally reflected from the cornea appears in the photograph as a blob of light called the eye spot. With appropriate calibration of the apparatus, the eye spot can be made to appear where the subject was fixating. Still or motion picture cameras can be used.

Corneal reflection has two basic limitations: The first is that the range of eye movements that can be studied is limited to about $\pm$ 12.5 degrees because only about that much cornea is exposed, and also because the cornea is not spherical at its periphery. The second limitation is lateral head movements which can have very deleterious effects.

In the most sensitive technique that has yet been devised to study eye movements, a contact lens is fitted over the cornea, and a light ray is reflected from a tiny plane mirror mounted on the contact lens onto a screen for direct observation or into a motion picture camera for a permanent record. Good records of eye movements of less than 10 seconds of arc have been obtained in this manner. However, the method's weaknesses include the probability of the contact lens and mirror interfering somewhat with normal eye movements. Also, it is difficult to prevent the contact lenses from slipping during saccades of five degrees or greater, and it is difficult to construct the contact lenses.

Still another technique of measuring eye movements is one which uses the changes in electrical potential between cornea and retina that occur when an eye moves. The potential changes are detected by electrodes placed above, below, and to the sides of the eye to measure vertical and lateral movements. A weakness of this method is that it is difficult to isolate the vertical and lateral movements from the two pairs of electrodes, and the potentials themselves are very small and may be obfuscated by large muscle-action potentials as well as external interference.

Photoelectric techniques have also been developed to study eye movements. Most of these techniques attempt to detect the position of the limbus, or boundary between sclera and iris, with beams of light, and to convert this information into an electrical signal that may be shown on an oscilloscope or recorded on magnetic tape. In one type of photoelectric measure, a light spot is swept rapidly back and forth across the eye. A photomultiplier picks up reflections of the spot. The spot is reflected differently from the white sclera than from the dark iris, and this causes the photomultiplier to have a high output when the spot is on the sclera, and a low output when it is on the iris. Horizontal eye position is indicated from measurement of the time that the spot begins to sweep across the eye, when it is on the sclera, to the time that the photomultiplier output drops as the spot crosses the limbus to the iris.

A recent development in photoelectric technique uses infra-red instead of visible light (Gaarder and Silverman, 1967). Another recent development, which shows great promise, is a device called the Oculometer (Merchant, 1967). The use of Oculometer has an advantage in that the subject's head does not have to be restrained, and there is nothing fastened to the subject's head or eyes. The device rests on a platform in front of the subject.

Young (1963) concludes in his paper that the contact lens-mirror method is the best for studying eye movements of less than one degree of arc, and that corneal reflection can also be used if saccades do not exceed ± 12 degrees. He recommends photoelectric devices as the most practical for measuring eye movements used in tracking a target or scanning a display over a range of one to 20 degrees of visual arc. He believes that electro-oculography is the best technique to use to measure eye movements greater than 20 degrees.

II

EYE MOVEMENT PARAMETERS IN SEARCH TASKS

The material in this section was drawn largely from two review-like papers, one by Mackworth (1967) and the other by Gould (1969). These two authors usually cite specific experiments when they make statements. In the present report the specific experiments will not be cited. An interested reader can obtain the appropriate reference from the papers if he is interested in a particular point.

Parameters in Fixation Location

As used here, fixation location refers to that part of the visual field at which a subject fixates or looks directly. The concept thus deals with spatial aspects of eye movements.

Gould reports that the type of task a subject performs will influence where he looks. For example, when subjects search aerial maps, they tend to cluster their fixations on the center of the maps, and to make progressively fewer fixations as the distance from the center of the maps increases. Radarscope operators searching for a dim flash of light that appears on the trailing edge of the scan line tended to fixate midway on the scan line rather than in the center of the radarscope. Other studies reveal that search patterns are not random, and frequently do not cover the display evenly.

The information that a subject has relative to a search task will also influence where he looks. Gould reports that, when an observer tries to find one target among many items on a display, search time is proportional to the total number of items being displayed. However, if the subject has specific information about the task, e.g., if he knows what color the target is, his search time is greatly reduced, and is proportional to the number of items the same color as the target.

A subject's purpose will also determine where he fixates. Gould reports work in which subjects were told to pay attention to various aspects of pictures. For example, they were told to estimate the material circumstance of a family in a picture. Fixations were found to be preponderantly on women's clothing and furniture, items that are used by many as criteria of material circumstance. If the subjects were told to remember what clothes the people in a picture wore, fixations appeared predominately on clothes.

Previous experience also helps to determine where a subject fixates. Gould reports a study which indicated that subjects reported more characters from the left side of tachistoscopic displays than from the right, which may be related to the fact that we read from left to right. McLaughlin, Kelly, Anderson, and Wenz (1968), in a study of perceived visual direction, state that quick motions and the appearance of definite targets in the periphery of the visual field will cause a saccade and resulting fixation in that part of the visual field. They agree with Gould and Mackworth that verbal instructions from the experimenter and the purpose of the subject help determine where the subject fixates.

Parameters in Fixation Sequences

Mackworth states that subjects are very consistent in selecting areas of a picture to inspect, but are inconsistent in the order with which they select these areas. He believes that people take their samples at random when they try to extract information from pictures, and that they assemble the data contained in the samples into a meaningful pattern after the sampling period is over. However, Gould thinks that fixation sequences are related to task characteristics. He states that subjects almost always fixate in a circular pattern when they monitor radarscopes, and that this pattern is caused by the rotating scan line. He reports work which shows that geometric similarity among patterns determines fixation sequencing when subjects make pattern comparisons. Finally, he reports a study that used a device which forced subjects to scan a map in a definite sequence. The results of the study showed that the subjects found a target in the map more quickly when allowed to scan in their own way rather than in the forced sequence. (Perhaps the "forced" sequence was merely inefficient; as noted previously, Gould stated that subjects do not fixate as much on the edges of a map as they do in the center. The temporal differences do not necessarily indicate that the subjects had a definite sequence of their own, only their own pattern, which could be random.) Mackworth and Gould thus do not agree as to whether or not subjects fixate in definite sequences. It may be that a task whose characteristics vary over time will induce particular fixation sequences, as in the case of monitoring a radarscope, but more experimentation is needed to answer the question more satisfactorily.

Parameters of the Useful Field of View

The useful field of view is the total area a subject searches to gain the information he wants. Gould reports one study in which the shape of the field was studied. In the study, the experimenters presented tachistoscopically a 9 x 9 grid of small white discs surrounding a central point on which subjects centered their vision. One disc was replaced by a triangle, and the subjects had to locate the triangle. The useful field of view was wider than it was high, and the subjects saw more triangles above the central point than below it.

In regard to the size of the visual field, Gould states that the size of the field is reduced when irrelevant information surrounds a target being sought, and that the size is reduced if the appearance of the entire display, including the target, is degraded, as it is when it is blurred. Mackworth reports substantially the same finding in a paper entitled, appropriately, "Visual Noise Causes Tunnel Vision" (Mackworth, 1965).

Parameters in Fixation Duration

Fixation duration refers to the length of time a person looks at something, or fixates. Gould states that task requirements and subject proficiency have been shown to influence fixation durations.

For example, highly trained inspectors of electronic parts had modal durations of 200 milliseconds, which approaches the minimum fixation time for the eye of 100 to 150 milliseconds. In a study in which less well-trained observers performed a less complex search task, modal durations were 250 milliseconds. In still another study, subjects looked for a dim flash of light behind the rotating scan line of a radarscope. The modal duration was 300 milliseconds.

Gould notes that fixation duration may be determined by the relation between the features of a target and items surrounding it. In one of his own studies, subjects had to identify a given pattern of dots (the target) in a collection of several patterns. Durations increased as the target became more similar to the other patterns in the collection of patterns. Other relative pattern features also caused durations to increase. However, the absolute features of a pattern had little effect on durations.

III

OPERANT CONDITIONING OF EYE MOVEMENTS

When the eye moves in a saccade to a given fixation point, the saccade can be thought of as producing a stimulus, namely, that which the eye sees when it is fixated. In this context, the saccade becomes an operant and should be, like any instrumental response, subject to the principles of operant behavior. Schroeder and Holland (1968) tested this hypothesis by having subjects detect a deflection of a pointer in one of four dials arranged in a square. When a subject saw a deflection of the pointer of any one of the four dials, he pressed a button to report that he saw the deflection.

The experimenters recorded eye movements on a Mackworth eye movement camera, which measures eye movements by corneal reflection (Mackworth and Thomas, 1962). They also used a Massey-Dickinson television digitizer in conjunction with a TV monitor to digitize the position of the eye spot. The digitizer located the brightest image on the TV screen, which in this system was the eye spot, and assigned the eye spot a number representing any one of 225 possible locations. Various recorders were used to provide permanent records of eye movements and button-presses.

Four reinforcement schedules were used to test each of three subjects. The first schedule reinforced low rates of responding in that a signal - a pointer deflection - only occurred after the subject had gone 10 seconds without looking at the dials. The second schedule was a fixed-ratio schedule in which a signal did not occur until the subject had looked at the dials 45 times (FR 45 schedule). A third schedule presented signals at two-minute intervals from the last-detected signal (FI 2-min.). The fourth schedule was a multiple of the other three.

The authors reported that, "In every case the reinforcement schedule came to control the rate of shifting or fixations into the dial areas." Cumulative response records presented in the report look like records of any instrumental response under control of a schedule of reinforcement. In the same year this report appeared, Berger published a report which showed that the eye movements of monkeys are also subject to reinforcement contingencies (Berger, 1968).

More recently, Schroeder and Holland (1969) have shown that saccades can be conditioned by concurrent variable-interval reinforcement schedules. In this study, subjects were successfully conditioned to look at certain areas of a display. The finding is pertinent to any attempt to train automobile drivers' eye movements because it shows that eye movements can be directed to various spatial locations. Obviously, drivers have to look at various parts of their visual field to obtain the information they need, and any training program would have to take this into account.

IV

DRIVERS' EYE MOVEMENTS

Literature Review

The first study in which automobile drivers' eye movements were measured was reported 10 years ago by Waldram (1960), who had subjects look at motion pictures taken from the driver's side of a moving vehicle. He used the Mackworth television eye-marker system (Mackworth and Mackworth, 1958) to monitor the eye movements of the subjects as they looked at the motion pictures. He was able to make permanent records of the subjects' scan patterns by photographing the television monitor with a motion picture camera. He found that the subjects' eye movements were similar, although one subject tended to fixate at shorter distances ahead of the vehicle than the other subject did. The subjects tended to fixate on the edges of vehicles they were "following", and tried to see farther ahead of vehicles being followed by looking over or past them. Peripheral as well as foveal vision seemed to be important to the drivers.

After Waldram's study, the next to be reported was one by Gordon in 1966. Gordon photographed the driver's visual field but did not use corneal reflection to mark the point of fixation in the field. He determined fixation locations by forcing the driver to look through apertures of varying size to obtain the information needed to drive. He then correlated aperture directions and locations with the filmed record to determine fixation points in the visual field. His measurements using this technique enabled him to conclude that road edges and center lane markers provide essential information for guiding the vehicle, that subjects differ in the way in which they obtain this information, that subjects do not have a fixed forward frame of reference, and that drivers shift their points of fixation when going from a left to a right curve.

Rutley and Mace (1968) used a still different technique to study drivers' eye movements in actual driving. They measured eye movements by recording changes in the corneal-retinal potential through electrodes placed on the temporal side of the eyes. The principal findings seem to have been that eye movement rates averaged about 130 per minute, and that the rates did not correlate with vehicle speed.*

Thomas (1968) used a Mackworth eye-movement camera of the same type used by Schroeder and Holland (op. cit.) to study drivers' eye movements. In an article in Scientific American, Thomas presented numerous pictures showing drivers' forward fields of view, with a light round dot (the eye spot) indicating quite clearly what a driver was looking at in a given

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*The Rutley and Mace study was unavailable to the reviewer, and the material was taken from a study by Whalen, Rockwell, and Mourant (1969).

instant. Thomas concluded that "Drivers use both direct vision (focusing on important objects) and peripheral vision (impressions of motion or light on the edge of the field of vision)."

The motion picture camera was mounted on the subject's head in Thomas' study, with the disadvantage that tall people could not serve as subjects. Further, the camera weighs several pounds and could restrict a subject's head movements - and presumably modify his "normal" eye-movement pattern as well as tire the subject.

The Studies of Rockwell and his Colleagues

In the same year that Thomas' article appeared, a technique for mounting the recording camera of the same type of system used by Thomas on a platform rather than on the subject's head was described by Rockwell, Overby, and Mourant (1968). The report revealed that the system could be calibrated to an accuracy of $\pm$ 1/2 degree in the horizontal direction and $\pm$ 1 degree in the vertical direction.

A great deal of research into drivers' eye movements has been produced by Rockwell and his colleagues since their apparatus became operational. In fact, they have produced almost all of the recent work, and this reviewer believes that they now lead the field. For this reason, several of their reports will be gone into in considerable detail.

A pilot study of drivers' eye movements, by J. T. Whalen, T. H. Rockwell, and R. R. Mourant. This was the first of the reports, and was published in April, 1968. Its purpose was to measure eye movements under several conditions of actual driving. The authors hypothesized that "characteristic eye-movement patterns can be identified and described for automobile driving," and that these patterns are a function of the driving task.

The apparatus was a model V-0165-IL4 head-mounted eye-movement camera made by Polymetrics Products of the Itek Corp. Polymetrics used the basic design of the 1962 Mackworth head-mounted eye-movement camera. Rockwell and his colleagues modified the Polymetrics apparatus so that the camera was mounted on a platform behind the driver, not on his head, as noted above.

Basically, the apparatus consists of a movie camera lens module fixed in position at the left temple of a subject by mounting the module on a head-piece worn by the subject, and of an eye lens module and light source fastened on the right side of the head-piece. In operation, the camera lens is focused so that the camera sees what the eye sees. A beam of light from the light source is directed to the center of the right cornea. The cornea reflects the beam to the eye lens, which in turn reflects it to a fiber optic cable which transmits it to a prism which also receives an image from the camera lens via another fiber optic cable. Images from both lenses thus become superimposed in the prism: the image from the camera lens is a picture of the scene at which the subject is looking and the image from the eye lens is the eye spot, which comes from the beam of light reflected from the cornea.

The light rays of the two images pass through the prism to the motion picture camera mounted behind the subject. Since the eye-spot is relatively bright, it is recorded on film as a white dot about one degree in diameter. When the subject moves his eyes, the light beam is reflected differently and the eye spot appears in different parts of the pictures. The eye spot appears where the subject looks because the beam is always projected from the source in the same direction.

In data analysis, the experimenters projected one frame of film at a time onto a screen. They could see where the subject was looking by finding the eye spot. To obtain quantitative data, they superimposed a grid on the picture on the screen. Figure 1 shows the grid, each square of which is one degree on a side. The intersecting lines in the grid represent the edges of the lane in which the driver's car was traveling: the left line represents the left lane marking lines and the right line represents the right edge of the highway. The point of intersection is the horizon. The grid was assumed to be vertical on the highway 50 feet ahead of the car. Note that the driver has only four degrees of vision below the horizon.

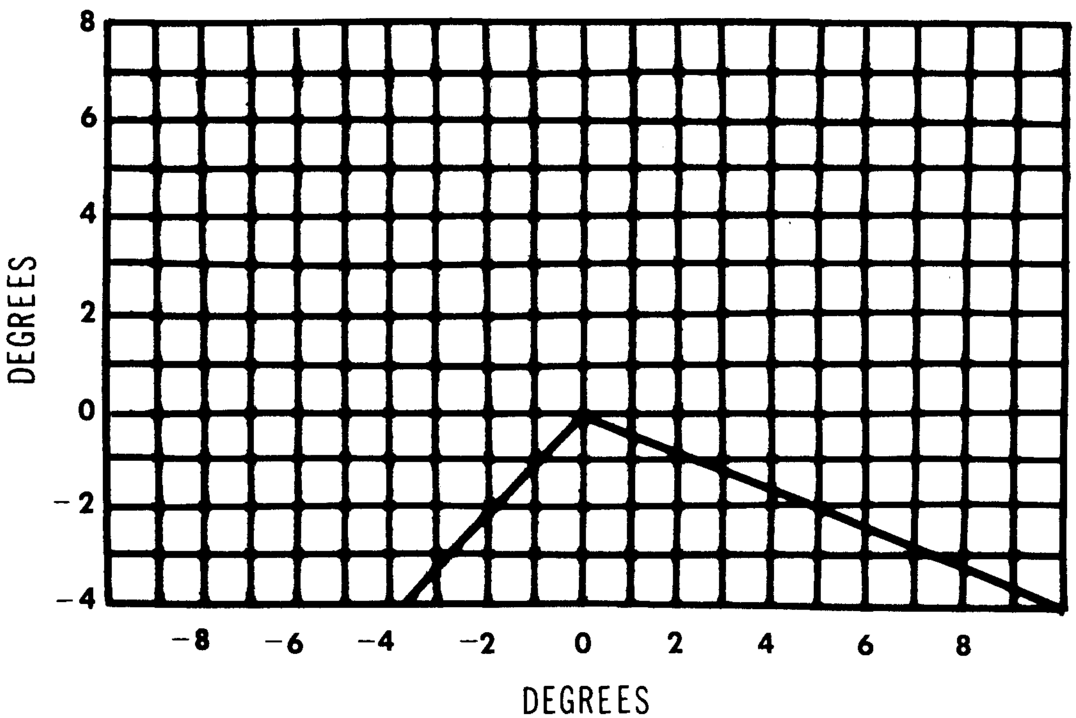

Figure 1. Data reduction grid.

Reference to Figure 2 illustrates how the vertical coordinate of the eye spot yielded a measure of how far ahead of the vehicle a driver was looking at a given time. If he happened to look along a line extending from his eye through -1 degree on the grid, he was looking 180 feet ahead. If he happened to look along a line extending from his eye through -2 degrees on the grid, he was looking 100 feet ahead, etc. When he looked straight ahead, i.e., fixated on the horizon, he was looking at a zero degree angle.

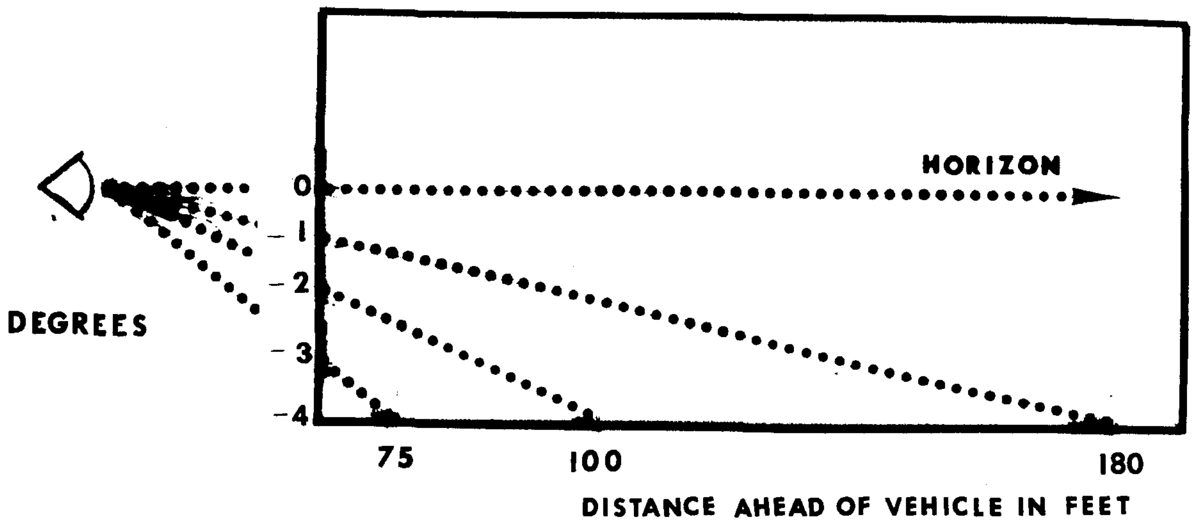

Figure 2. Viewing distance as a function of viewing angle.

Whalen _et al_ used this data analysis technique to produce "fixation density maps." These maps consist of listings of the percent of time a driver fixated in various grid cells during a test period. To get these percentages, the authors recorded the number of times the eye spot was in a given cell during a particular period of time, divided this number by the total number of fixations for that period, and multiplied by 100. Spatial patterns of fixations can be analyzed with these maps.

In their experiment, Whalen et al had subjects drive under six different driving conditions, recording eye movements during these times. The driving conditions were as follows: First, subjects drove as normally as they could on a typical freeway outside of a city at 50 mph for 3 minutes (this condition will be referred to as OR 50). In the second condition, the subject drove over the same course at 70 mph (OR 70). In the third condition he drove over the same route for three minutes but followed a lead car which started at 50 mph, accelerated to 70 mph, decelerated to 50 mph, accelerated to 70 mph, and finally decelerated to 50 mph. The subject was instructed to follow the lead car as closely as he could in dense freeway traffic in the city (driving condition CF SH, or car-following with short headway). In the fifth condition, the subject drove in city freeway traffic for three minutes, at "normal" freeway speed, which was about 50 mph (Traffic driving condition). The sixth driving condition is of no interest to this review, and therefore will not be considered.

Three male college students who were 20-23 years old and who had valid driver's licenses and safe driving records served as subjects. Each of them drove each of the five driving conditions twice except the Traffic condition which was driven only once. Eye movements were collected throughout each test run, with 81 minutes of data collected in the entire experiment.

The authors recorded fixation density maps for the five driving conditions, determined the numbers of fixations per unit of time, and measured fixation durations for the conditions. They also recorded vehicle velocities, steering wheel movements, and brake pedal movements during the tests to determine if these dependent variables were correlated with eye movements.

The fixation density maps showed that the distributions of fixations were of different sizes and shapes for the different subjects when averaged across subjects in the five driving conditions. Fixations in each of the maps were concentrated in a roughly defined central area with the numbers of fixations declining from center to periphery of the map. All of these general findings held true in the other studies of Rockwell and his colleagues in which fixation density maps were given.

Tables I and II summarize the fixation density maps. The reviewer calculated the values given in the tables from the original report's maps to provide a concise summary of the parameters of the fixation locations. Data for the tables came from Figures 3.10, 3.11, 3.12, 3.13, and 3.15 of the report.

Table 1. Modal Fixations in the Experiment of Whalen et al

Driving Condition	Modal Fixations (Vertical)	Modal Fixations (Lateral)
OR 50	.5 degrees above horizon	3.5 degrees right of center
OR 70	1.5 degrees above horizon	3.5 degrees right of center
CF SH	.5 degrees above horizon	4.5 degrees right of center
CF LH	.5 degrees above horizon	3.5 degrees right of center
Traffic	.5 degrees below horizon	4.5 degrees right of center

Table II. Viewing Areas in the Experiment of Whalen *et al*

Driving Condition	Total Cells	Pct. Fixations above Horizon	Pct. Fixations in Own Lane
OR 50	48	72	18
OR 70	46	92	5
CF SH	21	58	10
CF LH	27	73	16
Traffic	52	48	26

Table I shows that modal fixations for all driving conditions were about 0.5 degree above the horizon, which meant that the drivers generally fixated well ahead of the car as they drove. Modal fixations were about four degrees to the right of center in all conditions. (The center was an imaginary line extending from the center of the driver's forehead to the point on the horizon at which the two lane lines converged.)

Table II gives an idea of the patterns of fixations in the five driving conditions. The first column shows the numbers of cells with recorded fixations and thus indicates the size of the viewing area in a particular driving condition. For example, in condition OR 50, driving on the freeway out of town at 50 mph, fixations were recorded in 48 cells. This means that the viewing area in this particular condition embraced 48 of the one-degree squares in the data-reduction grid, or 48 square degrees.

Table II shows that there was a more restricted viewing area in car-following than in any other condition.* This might be expected since drivers must pay considerable attention to a car they are

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*Very few statistical significance tests were done in any of these studies. Conclusions about differences -- or lack of them -- were arrived at much more subjectively.

following, especially if that car does not maintain a constant speed. It is possible that there was a more restricted area in CF SH than CF LH (21 vs. 27 cells). Again, one might expect this since a rear-end collision can happen more quickly if a driver follows a car at a relatively short distance rather than a relatively great distance, and a driver, knowing this, monitors a car he follows at a short distance more closely than one he follows at a long distance and thus restricts his viewing area. The table also indicates little if any difference among any of the other driving conditions with respect to total viewing area.

Table II shows that most fixations were above the horizon in all driving conditions. A much greater percentage of fixations were above the horizon in OR 70 than in OR 50; there were 92 vs. 72 percent, respectively. It seems a reasonable finding that drivers look farther ahead when traveling faster. The same relationship of fixations above the horizon to vehicle speed might be expected in car-following, and the values of Table II reflect this in that there are 73 percent fixations above the horizon when the drivers followed the lead car at a "comfortable" distance and only 58 percent when they followed it as if they were in dense traffic. This latter finding is congruent with the finding that 48 percent of the fixation time was above the horizon in actual city freeway traffic.

The drivers apparently fixated more in their own lane when driving on the open road at 50 mph than when driving the same route at 70 mph. The meaning of this is not clear. The highest percentage of fixations in their own lane occurred when they drove in traffic; as Table II shows, 26 percent of their fixations were in their own lane in this condition. Perhaps this stemmed from a necessity to monitor the car's lane position more closely in traffic than in the other types of driving.

It should be noted that the fixation density maps in the original report of Whalen _et al_ revealed that there were virtually no fixations to the left of the driver's own lane in any driving condition. This is quite surprising. One intuitively feels that drivers do look to the left of the lane in which they are driving, at least occasionally.

Whalen _et al_ also reported differences in the distribution of fixation durations across subjects and driving conditions. More specifically, they plotted histograms of fixation durations at intervals of 0.2 seconds, and found differences in the shapes of the histograms and percentage values at particular intervals. It is difficult to reduce their analysis to tabular form, and so these distribution differences will not be considered here. However, it may be stated that the _modal_ fixation duration was 0.3 seconds in all driving conditions. And, of interest to later discussion is the finding that the _mean_ fixation duration for open-road driving was 1.7 seconds; for car-following, 1.8 seconds; and for traffic, .76 seconds. A somewhat related finding was that there were 34.5 fixations per minute in car-following, and 73.0 per minute in traffic.

The authors did not find any meaningful correlations between eye movements and vehicle velocities, steering wheel movements, or gas pedal movements.

Driver eye movements as a function of driving experience, by J. K. Zell. This report appeared in June, 1969, a little over a year after the Whalen et al report. The purpose of the study was twofold: to "compare drivers' eye movements from the time they begin driving until after they receive their permanent license," and to compare new drivers' eye movements with a "select number of experienced 'good' drivers' eye movements."

Zell's basic experimental procedure was to measure the eye movements of novice drivers shortly after they began driving, and to make additional measures as they gained experience. As an experimental control, he measured the eye movements of experienced subjects under the same driving conditions as those under which the novice drivers were tested. Apparatus, data collection, and data reduction were, as far as can be determined, identical to those used by Whalen et al.

Zell had the same five driving conditions that Whalen et al had, OR 50, OR 70 CF SH, CF LH, and Traffic. His routes were identical to those of Whalen et al, except for the Traffic condition. In that case a different section of the same urban freeway was used. Zell's test runs were three minutes, the same length as those of Whalen et al, but Zell only collected data for the middle 20 seconds of each minute, making a total of one minute's data per subject per driving condition, whereas Whalen et al collected data for the entire three minutes of a run. Zell collected a total of 100 minutes of eye-movement data in his experiment.

Four novice drivers were tested at one-month intervals for three months. Thus, each driver had four sets of measurements, or trials: the first, shortly after he began driving; the second, one month later; the third, two months later; and the fourth, three months later. They drove all five driving conditions on each trial. Two experienced subjects each drove the five driving conditions once. These drivers all had at least 20 years' driving experience. Testing and measurement procedures were the same as those for the novice drivers.

Zell's results were very difficult to review because the report contains many inaccuracies in plotting graphs and many arithmetical errors. There are also displeasing inconsistencies, e.g., the author gives fixation density maps for the experienced but not for the novice drivers.

Tables III and IV summarize the experimental data by which Zell compared beginning and experienced drivers. The reviewer took the material in Table III from Zell's Figures 11, 14, 16, 18, 19 20; and the material in Table IV from Zell's Tables 1 and 4. These data all deal with spatial aspects of the drivers' fixations. Zell had only one small table dealing with temporal aspects of the fixations, and parts of that table are discussed below.

Table III. Percentage of Time Subjects Fixated in Various Locations in Zell's Experiment

DRIVING CONDITION	Pct. Time Looking Ahead NI	N4	E	Pct. Time Out-of-View NI	N4	E	Other NI	N4	E
OR 50	52	75	43	21	8	35	27	18	22
OR 70	54	75	56	18	15	32	21	10	12
Traffic	50	58	46	16	11	36	34	31	18

DRIVING CONDITION	Looking at Lead Car & Center of Lane NI	N4	E	Out-of-View NI	N4	E	Right Edge Other NI	N4	E	Road Marker NI	N4	E
CF SH	58	69	71	5	4	8	28	19	11	10	9	10
CF LH	46	59	68	5	4	10	20	23	10	29	15	12

Table IV. Other Summary Data
from Zell's Experiment

DRIVING CONDITION	Pct. Fixations > 180 ft. Ahead of Car			Pct. Fixations < 180 ft. Ahead of Car			Pct. Time Looking Ahead of Car		
	NI	N4	E	NI	N4	E	NI	N4	E
OR 50	58	56	19	11	18	24	69	74	43
OR 70	45	58	43	26	17	13	71	75	56

Note the subheadings "N_1", "N_4", and "E" in the dependent variable columns of Tables III and IV. "N_1" refers to the first measurements made on the novice drivers, "N_4" refers to the fourth and last measurements made on the novice drivers, and "E" refers to the measurements made on the experienced drivers. Although Zell took four sets of measurements on the new drivers, he only reported the second set occasionally, and never reported the third set. He always reported the first and fourth sets.

The reviewer was struck at the outset by the fact that, in 12 of the 23 comparisons listed in Tables III and IV, the percentages for N_1 are more like the percentages for E than are the N_4 percentages. For example, in the "Pct. Time Looking Ahead" column of Table III, the novice subjects spent 52 percent of their time looking ahead of their car when first tested (N_1), and 75 percent when last tested (N_4). The experienced drivers (E) spent 43 percent of their time looking ahead, which is closer to 52 percent, or to N_1, than to 75 percent or to N_4.

The fact that N_1 was more similar to E in 12 out of 23 cases than N_4 was shows that, in these 12 cases, the novices were more like the experienced drivers when the novices were first tested than when they were last tested. In the other 11 cases, N_4 was more like E than N_1

was, which shows that, in those 11 cases, the novices were more like the experienced drivers when the novices were last tested than when the novices were first tested. All of this strongly suggests a random pattern as far as changes between N_1 and N_4 trials is concerned. More specifically, it suggests that the novices did not change their eye movement patterns at all in several months. Zell concluded that they did, in answer to his first experimental question.

Zell based most of his comparisons of new and experienced drivers on the measurements obtained in the last trial, or N_4 in Tables III and IV to answer his second experimental question. However, he evidently assumed that the novice drivers' eye movement patterns not only changed but approached those of the experienced drivers. For example, he presents a model that describes how eye-movement patterns change as a function of experience in his discussion. It was legitimate for him to compare N_4 and E under this assumption. However, the reviewer suggests that more accurate comparisons of novice and experienced drivers could be made by combining the N_1 and N_4 measurements.

Of interest to later discussion was the finding that the experienced drivers had mean fixation durations ranging from .16 second to .30 second in car-following.

Mapping eye movement patterns to the visual scene in driving: an exploratory study, by R. R. Mourant and T. H. Rockwell. This paper appeared in 1970 as a somewhat condensed version of an experiment which was part of a technical report that appeared earlier (Anonymous, 1969).

The technical report contains a little more data than the paper to be reviewed, but the paper is more concise and attention is therefore focused on it.

Mourant and Rockwell conducted the experiment to determine the effects of route familiarity on eye movements of drivers, to identify some of the visual cues used in driving, and to study differences between open-road and car-following driving. They used the eye-movement measuring apparatus used in the two studies just cited, and the same procedures of data analysis. They attempted to create differences in route familiarity by telling drivers to read all signs along a given route as if the drivers did not know the route; or by telling drivers to look at only those signs along the same route necessary to complete the route; or by telling drivers to try to drive the same route without reading any signs. The familiarity variable thus had three levels: the first, in which they read all signs, represented complete unfamiliarity; the second, in which they read only those signs needed to complete the route, represented moderate familiarity; and the third, in which they did not read any signs, represented complete familiarity. The route was a freeway in an urban area, and was perhaps the same used in the experiments of Whalen et al or Zell, although it was not stated in the paper or earlier report.

Mourant and Rockwell used two driving conditions. In the first, subjects drove in normal freeway traffic at 50 mph. This was called the open-road driving condition. In the second, driver subjects followed a lead car at 75 ft. which traveled at 50 mph. This was called the car-following condition. Each of eight young male subjects drove in the three familiarity conditions in each of the two driving conditions once, for a total of six test runs per subject. Two different but allegedly equivalent routes, designated A and B, were used so that the experimental design could be counterbalanced. Route A took 200 seconds to drive and route B took 180 seconds. Data were presumably taken during the entire time a subject made a test run. If so, the experiment produced a total of 144 minutes of eye-movement data.

As far as the familiarity variable was concerned the authors reported the results for all eight subjects only for open-road driving. They found that the mean location of the fixations for the eight subjects in the test runs in which the route was supposed to be "completely unfamiliar" was about 2.9 degrees above the horizon and about 4.2 degrees to the right of center (as before, center was an imaginary line extending from the center of the driver's forehead to the point at which the left and right lane markers joined at the horizon). In the "moderately familiar" condition the mean fixation location was about 2.2 degrees above the horizon and 4.2 degrees to the right of center, and in the "completely familiar" condition the mean fixation location was about 0.3 degrees above the horizon and 3.2 degrees to the right of center. The authors concluded that the mean fixation location varied as a function of route familiarity.

The authors treated their data from the car-following condition differently than the data for open-road driving. In car-following, they reported fixation density maps for one subject in each of the three familiarity conditions. They state that the map showed that there was an increase in "compactness" of the visual field from "completely unfamiliar" to "completely familiar." Inspection of the maps by the reviewer revealed that this seems to be true; the field of view for the "completely familiar" condition is more compact than the fields for the other two conditions. There was no apparent difference between the other two conditions. The authors do not say anything about the other seven subjects' performance in car-following.

Mourant and Rockwell use the changes in mean fixation location in open-road driving and the increase in "compactness" for the one subject in car-following to support a major conclusion that drivers' eye movement patterns varied as a function of route familiarity.

In evaluating this conclusion, it is noteworthy first of all that no tests of statistical significance were reported, and this is puzzling in view of the fact that the study had eight subjects. Second, the only findings leading to the conclusion that can be considered in evaluating the conclusion were those found in open-road driving. An assertion made on the basis of one subject is too tenuous to be evaluated.

In open-road driving, it should be noted first that the mean differences in fixation location between the first two familiarity conditions ("completely unfamiliar" and "moderately familiar") are unremarkable. The only difference is that the mean was 0.7 degree lower in the "moderately familiar" condition than in the "completely unfamiliar" condition. The mean difference between these two conditions and the "completely familiar" condition is more impressive (2.9 and 2.2 vs. 0.3 degrees). However, recall that the experimenter told the subjects to try not to look at any signs in the "completely familiar" condition. Signs are generally to the right and above the highway. If the subjects did not look at the signs, they probably did not look to the right of the highway and up as much as they would normally, and perhaps focused their attention to what was happening in their own and adjacent lanes more than they would otherwise. Thus, it is possible that the drivers did only what they were told to do, and that this in itself produced the observed differences. In other words, we cannot tell from the data whether or not drivers do or do not look at signs even if they are completely familiar with a route since "familiarity" in the experiment was defined only by the experimenters' instructions. We do know that subjects modify their eye-movement patterns in response to the experimenter's instructions, as noted earlier in the review of laboratory studies in Section II of this paper.

A second major conclusion of the study was that "The task of car-following induced a greater visual workload as indicated by increased sampling rates of lane markers and greater visual travel distances to examine road signs and other traffic." In regard to increased sampling rates of lane markers, the experimental data showed that the drivers made 7.4 fixations per minute on lane markers in car-following and 4.3 per minute on markers in open-road driving, a difference of 3.1 fixations per minute. However, the data also show that the drivers made a total of 196.0 fixations per minute in car-following and a total of 221.0 per minute in open-road driving, a difference of 25 fixations per minute. It is difficult to see how 3.1 more fixations per minute on lane markers in car-following increased the visual workload in car-following when there were 25 more fixations per minute in open-road driving even though the drivers' eyes may have traveled a little farther in scanning lane markers in car-following. The reverse would seem to be true.

The experimental data are also difficult to understand in regard to the assertion that there were greater visual travel distances to examine road signs and other traffic in car-following. Mourant and Rockwell state in their results that fixations on other vehicles were closer in front of the driver's vehicle in car-following than in open-road driving, and that lane-marker fixations averaged 75 ft. in front of the driver's car in car-following and 100 ft. in front in open-road driving. In their major conclusion they say that these findings meant that there were greater visual travel distances in car-following.

In evaluating the finding that there were greater visual travel distances in car-following, recall that the authors reported that there were 196 fixations per minute for car-following and 221 per minute for open-road driving. Of these totals, they also reported that 93.8 fixations per minute concerned stimuli such as other vehicles and road signs in car-following and most of these were on the lead car, while only 23.0 fixations per minute concerned the same stimuli in open-road driving. The rest of the fixations fell into an "other" category in both driving conditions. The "other" category was not defined. Thus over half of the total number of fixations per minute were unaccounted for--or at least unreported--in car-following and the vast majority were in the same situation in open-road driving. It would have been enlightening to see how visual travel distances compared in the two driving conditions if the "other" category had been considered. The reviewer finds himself unconvinced of the validity of the second major conclusion for this and the reasons given above.

Driver eye movements as a function of low alcohol concentrations, by B. L. Belt. This report was released in June, 1969. As the title indicates, its purpose was to study the influence of alcohol on drivers' eye movements. The author used the same apparatus and eye-movement measurement procedures as in the other experiments in the series.

In his experimental design, Belt had two different driving conditions at three levels of blood alcohol. Subjects drove on a freeway outside of a city at 60 mph for the first driving condition, and drove over the same stretch of road while following a car that accelerated and decelerated in a fixed pattern for the second driving condition. None of these conditions was the same as the other three experiments previously reviewed. The stretch of freeway was different, speeds in both driving conditions were different, and the car was different. The eye-movement measuring apparatus was the same, but Belt used different calibration procedures which, he said, "allowed considerably more accurate results than permitted in prior eye-movement studies" (p. 39). Thus it is virtually impossible to compare Belt's results with those of the other experiments.

The three alcohol levels were: A, no blood alcohol; B, 0.37 milligrams (mg) of alcohol per 100 milliliters (ml) of blood; and C, 0.75 mg of alcohol per 100 ml of blood. Two subjects were tested under each of the six experimental conditions (2 driving conditions x 3 alcohol levels). They drank vodka prior to the test runs in amounts appropriate to produce blood alcohol levels B and C. One subject replicated the design to provide reliability data.

Test runs in the open-road driving condition lasted 2-5 minutes each, with the time in a given run being determined by the time the experimenter needed to collect a one-minute sample of eye-movement data when the subject was not following any other cars closely and when no car cut in front of the subject's car. Runs in the car-following condition lasted about 3 1/2 minutes, with eye-movement data apparently being collected during the entire run. If the 3 1/2 minutes figure is correct, a total of 40 1/2 minutes of eye-movement data was collected, including the replication by one of the subjects.

Belt concluded that alcohol was "associated with increased eye fixation durations in the open-road driving at least." And, "In addition, the subjects studied appeared to exhibit a narrowing visual perception that increased with alcohol blood concentration." The principal data from which these conclusions were drawn is reproduced in Table V.

The dependent variables in Table V are as follows. Mean fixation duration, given in units of a second, is a measure of the average time a fixation lasted in the two subjects. Mean travel distance, given in

TABLE V: Six Dependent Variables in Belt's Experiment at the Three Alcohol Levels

Dependent Variable		Open-Road Driving A	B	C	Car-Following A	B	C
Mean Fixation Duration, sec.		.15	.21	.22	.26	.25	.27
Mean Travel Distance, deg.		1.55	1.62	1.67	1.20	1.24	1.18
Pct. Time Out-of-View		38.6	37.4	24.2	10.4	9.2	3.3
Concentration Index		35.3	37.1	48.7	76.3	70.1	80.1
Cumulative Percent	1 deg.	0	0	0	0	0	0
Travel Distances, at	2 deg.	79	79	75	94	91	95
1, 2, and 3 Deg.	3 deg.	91	90	90	98	99	100
Cumulative Percent	.25 sec.	83	66	68	59	62	57
Fixation Durations,	.50 sec.	96	91	92	86	89	89
at .25, .50, 175	.75 sec.	99	97	98	94	97	94
and 1.00 sec.	1.00 sec.	100	98	100	97	99	99

A = no blood alcohol
B = .37 mg alcohol per 100 ml blood
C = .75 mg alcohol per 100 ml blood

degrees, is a measure of how far the average saccade traveled. Percent time-out-of-view is a measure of how long the eye-spot was out of the camera's view in a given test run. The concentration index was obtained by taking the total time that fixations appeared in the most populous 3 degree x 3 degree block of the data reduction grid, dividing this by the total maneuver time, and multiplying the resulting number by 100. The two cumulative percent variables are self-explanatory. All of the values in the table are averages for the two subjects, and were calculated by the reviewer since Belt reported scores separately for each subject.

For open-road driving, the fixation duration and travel distances appeared to increase with increasing blood alcohol. The differences among the three levels of the alcohol variable, i.e., among levels A, B, and C, are small in the cases of both dependent variables. (Belt tested the fixation duration variable and reported no statistical significance, but did not report a significance test on the travel distance variable). Percent time-out-of-view appeared to decrease rather abruptly from blood alcohol level B to level C. Belt reported no significance test on this measure, but stated that "the decrease in out-of-views hinted the subject was spending more time on the data-reproducible grid." This caused him to devise his concentration index, which showed the same general pattern as time-out-of-view, except that it increased, and, it was reported, showed "overall" statistical significance at the .016 level. From this, he concluded that "increased amounts of alcohol caused the subjects to concentrate their field of vision." The two cumulative percent variables showed no discernable pattern.

In considering the conclusions stated above regarding the effects of alcohol on eye movements on open-road driving, it should be noted that Belt reported statistically significant differences in only one dependent variable, the concentration index. This significance was reported to be "overall." It probably stemmed from the relatively large difference in concentration index between blood alcohol levels B and C.

Even if the lack of statistical significance in all but the concentration index measure is ignored, and patterns of differences are relied on, it is still difficult to come to any firm conclusions about the effects of alcohol on eye movements because the patterns themselves are inconsistent. In the case of fixation durations, the increase occurred only between level A (no alcohol in the blood) and levels B and C (.37 and .75 mg alcohol per 100 ml blood respectively). There was no appreciable change between levels B and C. Are we to conclude that any amount of alcohol in the bloodstream has the same effect on fixation duration?

Referring again to Table V, it can be seen that mean travel distance increased in a straight line from levels A through C. Percent time out-of-view showed a different pattern than either fixation duration or travel distance; there was no appreciable difference between levels A and B, but there was a relatively sharp decrease in percent of time out-of-view from level B to level C. The concentration index showed no appreciable difference between levels A and B, and a sharp increase from B to C. Patterns of differences seemed to be random with respect to the two cumulative percent dependent variables.

Why alcohol should affect the six dependent variables differently is unclear. For this reason, and for the general lack of statistical significance, the reviewer does not feel that Belt's conclusions regarding the effects of blood alcohol on eye movements are warranted.

Belt did not conclude that alcohol caused differences in eye movements in car-following. Examination of Table V quickly reinforces this lack of conclusion. However, he did conclude that there were differences in eye-movement patterns between open-road and car-following driving because the open-road mean travel distance was greater than for car-following, and the difference was statistically significant at the .001 level. This conclusion has been noted in the studies previously reviewed.

Comparisons of the studies of Whalen et al and Zell. These two studies had the most in common and thus the comparisons will be the most extensive. Tables VI and VII summarize the major results of the two experiments. The numerical values for the Whalen et al study appeared previously in this report in Tables I and II, but are reproduced again for easy comparison with Zell's data.

The data for Zell's experiment presented in Tables VI and VII were calculated by the reviewer from fixation density maps of the experienced subjects as contained in the original report; as previously noted, fixation density maps were not given for the novice drivers. As far as can be determined from the reports, the only differences between experimental conditions for all subjects in the Whalen et al study and for the experienced subjects in Zell's study were that a slightly different

TABLE VI: Modal Fixations in the Experiments of Whalen *et al*. and Zell

Driving Condition	Modal Fixations Whalen	(Vertical) Zell	Modal Fixations Whalen	(Lateral) Zell
OR 50	.5 deg. above horizon	.5 deg. below horizon	3.5 deg. right	1.5 deg. right
OR 70	1.5 deg. above horizon	.5 deg. below horizon	3.5 deg. right	1.5 deg. right
CF SH	.5 deg. above horizon	.5 deg. below horizon	4.5 deg. right	2.5 deg. right
CF LH	.5 deg. above horizon	.5 deg. below horizon	3.5 deg. right	1.5 deg. right
Traffic	.5 deg. below horizon	.5 deg. below horizon	4.5 deg. right	2.5 deg. right

TABLE VII: Viewing Areas in the Experiments of Whalen *et al*. and Zell

Driving Condition	Total Cells with Fixations Whalen	Total Cells with Fixations Zell	Pct Fixations Above Horizon Whalen	Pct Fixations Above Horizon Zell	Pct Fixations in Own Lane Whalen	Pct Fixations in Own Lane Zell
OR 50	48	68	72	2(15)	18	39(12)
OR 70	46	77	92	16(32)	5	31(12)
CF SH	21	40	58	6(9)	10	74(9)
CF LH	27	45	73	18(16)	16	64(8)
Traffic	52	95	48	23(28)	26	17(19)

stretch of urban freeway was used in the in-town traffic driving condition, and that the two experienced subjects in Zell's study had more driving experience than any of the subjects in the Whalen et al study. Even with these differences it should be possible to compare the two studies confidently to determine consistencies and inconsistencies.

One point about Table VII should be clarified before the two studies are compared. When Whalen et al reported their fixation density maps, every cell that had an entry had at least one percent as the value. On the other hand, when Zell reported his fixation density maps, every cell that had an entry had either a dot meaning "less than one percent of the fixations were in this cell" or, if the percentage of fixation time in a given cell was one percent or more, the actual numerical value was given. Table VII lists the number of cells that had less than one percent fixation time in parentheses. For example, in Zell's study in condition OR 50, two percent of the driver's fixations were above the horizon definitely, with 15 additional cells above the horizon having entries. If the 15 additional cells had an average of 0.5 percent fixation time each, total fixations above the horizon in this case would be 2 plus 7 1/2, or about 9 1/2 percent.

Table VI shows that modal fixations in the study of Whalen et al were a half degree or more above the horizon in every case except one, while modal fixations in the Zell study were always a half degree below the horizon. It is clear that a definitive statement about whether or not subjects tend to look above or below the horizon cannot be made from these data. Modal fixations in the lateral direction were to the right of center in the studies of both Whalen et al and Zell, but were about two degrees farther to the right in the Whalen et al study. Apparently drivers center their fixations to the right of center, but that is all that can be said.

Table VII shows that there was a more restricted field of view in car-following than open-road or freeway driving in both studies as measured by the total number of cells with recorded fixations. In fact, the field of view was, roughly, only about half as big in car-following, as is illustrated by the findings of the Whalen et al study that the total cells with fixations averaged 24 for car-following, 47 for open-road driving, and 52 for driving in traffic. The field of view was most extensive in the traffic condition in both studies.

Table VII also shows that the field of view, as illustrated by the data in the Total Cells with Fixations column, was much greater in all driving conditions in the Zell study than in the Whalen et al study. In fact, the fields of view in Zell's study were nearly twice as extensive in most cases.

The percentages of fixations above the horizon given in Table VII show similarities and differences between the two experiments. The two studies are similar in that the subjects fixated more above the horizon when driving at 70 mph than when driving at 50 mph [92 vs. 72 percent fixation time in Whalen et al and 16(32) vs. 2(15) in Zell]. Similarly, more fixation time was spent above the horizon in both studies when car-following with a long headway than when car-following with a short headway [73 vs. 58 percent in Whalen et al and 18(16) vs. 6(9) in Zell].

However, there were marked differences between the two studies as far as total percentages of fixations above the horizons were concerned. In all driving conditions, Zell's subjects fixated much less above the horizon than did the subjects in the Whalen et al study. The modal differences described above reflected this, but did not in themselves indicate how greatly different the drivers' fixation patterns relative to the horizon actually were in the two studies.

Similar differences between the two studies are indicated in Table VII in the listings of percentages of times the drivers fixated in their own traffic lane. In every condition except Traffic, Zell's drivers spent more time looking in their own lane. Table VII shows that the figures are scarcely comparable in the case of car-following; the drivers in the Whalen et al study spent only 10 and 16 percent fixation time in the short and long headway conditions, and Zell's drivers spent 74(9) and 64(8) percent fixation time in the same two conditions. Assuming 0.5 percent fixation time for each cell that had less than one percent fixation time in Zell's study, the car-following fixation percentages become 74 + 4 1/2 = 78 1/2 and 64 + 4 = 68 percent for the two conditions.

The greatest similarity between the two studies in terms of fixations in the drivers' own lane appeared in the Traffic condition. In this condition, the drivers in the Whalen et al study fixated 26 percent of the time in their own lane, and Zell's drivers fixated 17 + 9 1/2 = 26 1/2 percent of the time in their own lane. The vertical modes in the Traffic condition were the same in both studies, 0.5 degrees below the horizon; the drivers used the greatest viewing area of any in the Traffic condition, 52 cells in the Whalen _et al_ study and 95 in Zell's study; and the percentages of fixations above the horizon were the most alike in the Traffic condition, 48 percent in the Whalen _et al_ study and 23 + 14 = 37 percent in Zell's study.

One final comparison that can be made between the two studies is not indicated in Tables VI and VII. The subjects of the Whalen _et al_ study almost never fixated to the left of their own lane as stated earlier in the report. It has not been previously stated, but is a fact that Zell's drivers frequently fixated to the left of their own lane. The question of whether or not drivers look to the left of their own lane is obviously unanswered by these two experiments, but the reviewer favors Zell's findings on a purely intuitive basis.

Comparison Among all of the Reviewed Studies of Rockwell and His Colleagues. Comparison of all the studies to determine consensus for number of fixations per minute is very difficult because these numbers were reported only in the studies of Whalen _et al_ and Mourant and Rockwell. One comparison can be made in these two cases, and that is the number of fixations per minute for the freeway traffic condition. As noted earlier, Whalen _et al_ found 73.0 fixations per minute in traffic, and Mourant and Rockwell found 221.0 per minute. The difference here is obviously too great to make any definitive statement. Further discussion of the point is given later in this review.

Consensus regarding fixation durations is easy to achieve. The _mean_ duration across all driving conditions in the Whalen _et al_ study was 1.4 seconds but the mode was 0.3 second in all conditions. Zell's range of durations was .16 second to .30 second for experienced drivers. The mean duration in Mourant and Rockwell's study, as given in the report on which the reviewed paper was based, was .29 second, and Belt's mean, calculated from Table V, was .23 second. Assuming that the mode in the Whalen et al study was a more accurate representation of the average than the mean, all studies agree that fixation durations in the driving conditions tested were relatively short, from .16 second to .30 second, with the mode of this distribution being near .30 second than .16 second.

V

DISCUSSION

Surprisingly little experimental work has actually been done to measure drivers' eye movements in view of the importance of vision to driving. One thing that has undoubtedly held potential investigators back has been the lack of measuring equipment. This bar to study is being lowered rapidly with the development of measuring devices such as the eye-movement camera used by Thomas and by Rockwell and his colleagues. Some of the photoelectric techniques may prove to be easily adaptable to automobiles, and they may add a new dimension to measuring drivers' eye movements because of the possibility that they can be used without attaching anything to the subject's head.

Most of the work that has been done in the area has been done by Rockwell and his colleagues. They have used their modified Mackworth-type eye-movement marker successfully in studying drivers' eye movements. However, they have had to reduce their data manually, and this has severely limited them as to the amounts of data that could be dealt with. They have been forced to use small numbers of subjects and short test runs, and this in itself makes statistical testing of results difficult if not impossible because so little individual difference within and among subjects can be tolerated. (For that matter, any type of analysis is difficult with small N's and short runs.) The reviewer believes that automatic data reduction is absolutely essential if this kind of work is continued. With it, numbers of subjects and test periods can be increased to provide more reliable data.

All of the driving studies of Rockwell and his colleagues, and all of the studies that appeared prior to those of Rockwell and his colleagues have indicated that drivers do not sample the total available visual field equally. This can be seen most clearly in the fixation density maps of Rockwell and his colleagues which show that fixation distributions are patterned, with the greatest percentages of fixations appearing in a central area and the lowest percentages appearing at the periphery of the distribution.

Perhaps the closest thing to a general fixation pattern, i.e., a pattern appearing in all driving conditions, was the drivers' tendency to center their visual fields to the right of an imaginary line that extends from the middle of the forehead to the point at which the right and left lane markers seem to converge at the horizon. However, the driving studies did not reveal whether or not subjects generally tend to fixate above or below the horizon since there was considerable inconsistency in regard to this point.

Drivers appear to diminish the size of their visual field when following a lead car, and to enlarge the field when driving without attempting to follow a particular vehicle. Perhaps stimuli other than the lead car become irrelevant when the driver specifically tries to follow the lead car, and the diminishment is of the same type as that observed by Gould and Mackworth (cf. Section II, Parameters of the Useful Field of View). No quantification of this phenomenon is possible at the present time, although there was a hint in the data that the field was more restricted when the driver followed a lead car closely than when he did not. The size of the visual field seemed to be greatest when the drivers were in freeway traffic in an urban area. The studies did not reveal any consistent data regarding conditions which cause drivers to fixate in their own lane, or on signs, road markers, or any particular stimulus other than a lead car. However, there was a suggestion that drivers have different fixation patterns when they know a route with varying degrees of familiarity, although it is possible that this finding was produced by the experimenter's instructions as to where to look or not to look, and not by familiarity since familiarity was defined solely by the experimenter's instructions.

The consensus of the driving studies was that average fixation durations in all driving conditions ranged from .16 second to .30 second, with the mode nearer .30 second than .16 second. These findings are similar to the durations of 0.2 to 0.3 seconds reported by Gould for search tasks, and it is therefore assumed that they are valid.

The driving studies do not agree as to what the rates of fixation are in driving. Rutley and Mace reported a rate of about 130 fixations per minute, Whalen _et al_ reported rates ranging from 34.5 to 73.0 per minute, and Mourant and Rockwell reported rates ranging from 196.0 to 221.0 per minute. It is difficult to decide which of these rates are the most typical since they are obviously so very different.

It was noted earlier that Gaarder reported that rates range from 120 to 240 fixations per minute in general viewing. The rates found in the Whalen _et al_ study are clearly outside of this range, while the Rutley and Mace and Mourant and Rockwell rates are within it. It is therefore probable that rates of fixation are somewhere between 120 and 240 per minute, but more experimentation is needed to settle the argument.

There was no evidence in the driving studies that good and poor drivers' eye movement patterns differ; in fact, there were no studies that investigated the question specifically. Zell compared novice and experienced drivers, which may be related to the question, but the reviewer feels that his results were inconclusive. Experimentation is needed to compare good and poor drivers' eye movements, and to compare novice drivers' eye movements with those of good and poor drivers. This work should be done after basic patterns or functional relationships between eye movements and visual stimuli have been established under controlled conditions. Work with factors such as alcohol, fatigue, drugs, etc., should also be done after the basic patterns have been established, and training of eye movements using operant conditioning techniques should be considered after the basic patterns are established.

VI

CONCLUSIONS AND RECOMMENDATIONS

1. Very little is known about drivers' eye movements at the present time. However, the area is promising, and will undoubtedly be investigated by increasing numbers of people, especially as corneal reflection, photoelectric, and perhaps even electrooculographic measuring devices become more efficient. Research in the area is recommended.

2. The Mackworth-type eye-movement camera is a satisfactory measuring device, although the camera should be mounted somewhere other than on the driver's head. However, photoelectric devices such as the Oculometer should be considered before investing in a Mackworth-type camera. It is possible that the Oculometer cannot be made operational for several years, or that it will cost too much, but it should be considered because it can be used without anything being fastened to the subjects' head or eyes.

3. Automatic data reduction is an absolute necessity no matter what type of measuring device is used. Without it, data reduction is laborious and time-consuming, and this severely limits the number of subjects and data collection periods of experiments. A device such as the Massey-Dickinson Television Digitizer, used by Schroeder and Holland with their Mackworth-type eye-movement camera, should definitely be considered if an investment into an eye-movement camera is made.

4. Eye-movement patterns of drivers must be established in controlled conditions. We must know whether or not there is a basic pattern of eye movements, and we can only discover this through controlled conditions. For example, a basic set of experimental conditions might be a straight stretch of highway with no distractions such as other vehicles and signs. Once the patterns are established under these

conditions, other factors such as vehicles and signs can be introduced to determine what happens to the basic patterns. Experimental control is not impossible to achieve; even on the highway.

5. Once basic eye-movement patterns are established, presumably from studies using good drivers, determinations can be made as to whether or not the patterns of these good drivers differ from those of poor or those of beginning drivers. Determinations can also be made of the effects of fatigue, alcohol, and other factors on the basic patterns.

6. If there are marked differences between the ways in which good, poor, and beginning drivers move their eyes while driving, attempts should be made to train the poor and the beginning drivers to move their eyes in the same patterns as the good drivers. It is recommended that training with operant conditioning techniques be considered because these techniques have been successful in controlling eye movements of both human and animal subjects.

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APPENDIX E

UTILIZATION OF INSTRUMENTED CARS PROJECT PRELIMINARY EVALUATION*

*Prepared by Dr. Norman A. Coulter, Jr., University of North Carolina Biomedical Engineering and Mathematics Department and submitted to Highway Safety Research Center on July 7, 1970.

I. Brief Review of Literature and Synthesis.

The Drivometer is based on a theory of traffic stream flow and level of traffic service proposed by Greenshields and Platt. The theory is open to criticisms but it is really not essential to the Drivometer which measures certain quantifiable features of driver performance. Of these, fine steering reversal rate was judged to be the most sensitive indicator.

The measurement of heart rate (HR) and galvanic skin response (GSR) is open to serious question. How reliable is the heart rate as determined through the steering wheel sensor? Muscle artifacts could produce errors -- giving spurious signals. The technique of indicating a GSR event seems worthless.

The paper by Simonson, et al., has not yet been reviewed but it would seem to be highly significant.

II. Suggestions for Supplementary Instrumentation.

A. For some research studies, it is suggested that one car be provided with facilities for measuring and recording analog physiological data. This might include the following:

1. Electrocardiogram (ECG)
2. Galvanic skin response (GSR)
3. Electroencephalogram (EEG)
4. Respiration (R)
5. Blood pressure monitor (BP)

An analog tape recording system would be required to record these data. It is possible that the tape deck now in the car could be utilized for this but it probably would be better to have a separate system.

The ECG could be used not only to provide reliable heart rate data (provided electrodes attached to the subject were used) but would provide additional information of interest, such as extrasystoles, elevated ST segments, etc. Serendipitously, ECG response to controlled stress in the test course might be very useful as a screening procedure for detecting incipient coronary heart attacks. This could be of considerable medical value, since measures could be taken to prevent or postpone such attacks or minimize their severity if they do occur.

Electrodes attached to the sternum and left side of the chest would probably be preferable, but right arm-left (with ground on right leg) would be acceptable.

Attempts to correlate EEG waveforms with subjective states have not in general been very effective. Nevertheless a number of powerful mathematical techniques are available and computers now make their use practical. Empirically, the following very rough correlations are sometimes made.

Band	Frequency (cps)	State
Delta	less than 4	Sleep
Theta	4 - 8	Emotional arousal
Alpha	8 - 13	Awake but relaxed (eyes closed)
Beta	greater than 13	Alert, active

It might be useful to study EEG in some subjects using these analytical techniques (power spectral density function, for example) to see if any correlation with state of alertness of the driver could be ascertained.

B. It is recommended that the steering wheel not be used for heart rate data unless unavoidable. Instead, ECG electrodes should be used, as described above. In addition to the questionable reliability of heart rate data obtained with the steering wheel, a considerable amount of data are lost when one hand is off the wheel.

It is also recommended that the steering wheel not be used for GSR event indication. Perhaps the gold can be salvaged to help defray some of the costs of the project!

III. <u>Suggestions regarding the test course</u>.

A. It is suggested that the test course include a "double-blind sequence" of hazards. By this it is meant that one hazard be presented requiring a certain response from the driver, followed by a second hazard that is accentuated by his probable response to the first. This might be difficult to arrange, but it is the kind of situation that is very conducive to serious accidents. The risks, of course, would have to be well controlled.

B. It is suggested that consideration be given to measurement of total reaction time of the subject to various test situations. The instrumentation for this is either available or readily introduced, but it does not appear to have been considered in the Drivometer studies. This might be a very important measure to obtain; from this measure it might be possible to derive a "maximum safe speed" for a given driver, for example.

C. It is suggested that for some studies it may be useful to compare driver behavior with and without the presence of an accompanying observer.

IV. Suggestions regarding base-line data.

A. It is suggested that consideration be given to correlating performance as a function of difference of the test car from the car the driver is familiar with.

B. Since heart rate varies with respiration, it may be useful to obtain a base-line of heart rate response to breathing over a range of frequencies and amplitudes. This might later be used to separate the respiratory sinus arrhythmia from the recorded heart rate, so as to obtain a more accurate measure of response of heart rate to stress.

C. A 30-minute period of collection of physiological data on the subject in the car is suggested in order to have an adequate control record. In view of high individual variability, the subject should be his own control, as much as possible.

D. Standard psychological reaction times would also be useful for comparison with total reaction times in the test car.

V. How can drivers be discriminated?

A. Heart rate response to a sudden stress may be better quantified by separating the respiratory heart rate response. Also, the time to return to normal may be a more significant indicator than the magnitude of the heart rate change.

B. Total reaction time to a standard test situation might be useful. For example -- with the driver approaching a stop light at a given speed, a light change might be triggered at a known distance from the light. Time to application of brake pedal could be precisely determined.

C. Previous studies indicate steering rate reversals are a sensitive indicator which might be a useful discriminator.

D. Comparison of driver behavior the second or nth time over the course might yield discriminators of "ability to learn" or "adaptability to repeated stress."

APPENDIX F

SAMPLES FROM DATA MANUAL

EXAMINERS' SCHOOLS 1 AND 2

Physical Plant Tests

Purpose: To determine the relationships among recorded variables over two different courses - open and closed. Additionally, to examine differences in driving pattern as a function of the type of closed course configuration driven and the number of times each was driven.

Procedure: Each subject drove a single car 3 times each over two configurations of a closed course and once over an open course accompanied by the same experimenter throughout.

Greenwood Course Tests

Purpose: To acquire data over a standard course from drivers oriented toward safe and correct driving for comparison with data from other drivers on the same course.

Procedure: Each subject drove the course for one unrecorded practice trial during which the experimenter indicated the route. The subject then drove 2 additional times during which data were collected.

The major factors of interest are:

1. Course
2. Configuration
3. Trial
4. School 1 vs. School 2 for Greenwood Course

RELIABILITY STUDY AT THE STATE FAIRGROUNDS

Purpose: To determine to what extent and for which variables differences exist between cars and between experimenters. Additionally, to examine group, order and driver effects.

The following diagram illustrates the basic experimental design of this study:

	G	R	W
J	A	B	C
S	B	C	A
D	C	A	B

where: G, R and W refer to the Green, Red and White Cars

J, S and D refer to the experimenters Joe, Steve and Dan

A, B and C refer to three drivers serving as subjects

Three drivers were tested at a time and there were eight replications for a total of 24 subjects.

The order of testing was as follows:

Run 1: AJG, BDW, CSR
Run 2: ASW, BJR, CDG
Run 3: ADR, BSG, CJW

which indicates the specific combinations of Driver, Experimenter and Car per run: Six subjects were tested in the morning and six in the afternoon of one day. One week later 12 additional subjects were tested in the same manner. The course driven and other conditions were the same for all subjects. Each subject drove 3 times around a .33 mile paved 4-block section of fairground streets in an essentially figure-8 pattern that provided for an equal number of right and left turns.

ROAD TESTING -- DRIVER LICENSE IMPROVEMENT PROJECT

Instrumented Car Data

This is an organization of the various tasks related to the processing and analysis of instrumented car data.

General information is provided concerning the stages of data treatment, coding format and the variables involved. Specific information details the coding format, study design, variables of interest and proposed statistical analyses for particular sets of data.

A special concurrent task involves the development of a unified data reduction and statistical program for the complete local processing of instrumented car taped data.

A. Stages of Data Treatment (See flow diagram)

1. Collection of raw data on:

   a. Counters
   b. Tape
   c. Supplementary data forms
   d. Driving record
   e. Other

2. Coding

3. Keypunching and verification

4. Checking punched cards against raw data

5. Listing raw data via computer

6. Preparing graphs as requested

7. Computing descriptive statistics

8. Conducting appropriate statistical tests on variables of interest

9. Rearranging, combining, deriving variables and retesting as desired

10. Preparation of summary statistical tables including:

    a. Kind of test
    b. Variables contrasted
    c. Value of statistic
    d. Significance level

B. Coding Format

Each subject's data will require N number of cards depending upon the kinds and sources of his data. Each card shall contain the driver's license number, his primary identifier, which shall serve as the key to all of his data. In addition, other identifiers shall be included to specify the particular set of conditions under which the data were obtained.

Card 1. Contains data from the counters and additional hand-scoring of variables such as cone knockovers, correct-incorrect responses, etc. (See copy of General Coding Format)

Card 2. Supplementary data and HSR forms combined. Includes biographic, traffic and weather information. (See copies)

Card 3. North Carolina Driving Record. Includes data relating to accidents and violations. (Coding format in preparation)

Card 4. Tape. (See copy)

Card N Other data as the need is determined.

C. Variables

1. Dependent variables

a. Recorded variables (from counters or tape)

(1) Total time
(2) Run time
(3) Distance
(4) Speed change
(5) Fine steering reversals
(6) Coarse steering reversals
(7) Accelerator reversals
(8) Brake applications

b. Derived variables

(1) Each 1/100th of a minute (Tape only)
(a) Momentary speed (Average mph)
(b) Percent time one hand off steering wheel
(c) Time brake is applied
(d) Time accelerator not being used
(e) Fine steering reversal rate
(f) Time that vehicle is stopped

(2) At end of test period (File, sub-total)
(Tape = T; Counters = C)
(a) Average speed T and C ($T \neq C$)
(b) Speed change rate T and C
(c) Accelerator reversal rate T and C
(d) Brake application rate T and C
(e) Average fine steering rate T and C ($T \neq C$)

(f) Average GSR rate T
(g) Average heartrate T
(h) Average percent time one hand off T
(i) Average coarse steering rate T and C ($T \neq C$)
(j) Brake Mn/Mn T
(k) Accelerator off Mn/Mn T
(l) Heartbeat standard deviation T
(m) Heartbeat average of averages T
(n) Heartbeat range T
(o) Fine steering reversals standard deviation T
(p) Fine steering average of averages T
(q) Fine steering range
(r) Speed (Mph) standard deviation T
(s) Speed average of averages T
(t) Speed range T
(u) Fine steering rate adjusted T and C
$FS_{ADJ} = FS_{TOTAL} - CS_{TOTAL}$ *

c. Hand scored variables

(1) Cone knockovers
(2) Distance
(3) Hits
(4) Misses
(5) etc.

d. Driving record variables

(1) Violations
(2) Accidents

2. Independent variables

a. Biographic variables

(1) Age
(2) Sex
(3) Race
(4) Education
(5) Occupation
(6) Year of first driver's license
(7) Year of first N. C. driver's license

b. Vehicular variables

(1) Make and model of car subject usually drives
(2) Year of car
(3) Kind of transmission
(4) Kind of steering
(5) Kind of brakes

*The same variables can be derived from counter data as from tape data where only <u>totals</u> were used. For example, $FS_{RATE} = FS_{TOTAL} / \text{RUN TIME}_{TOTAL}$

c. Driving variables

(1) Miles driven per year
(2) Miles driven at night
(3) Miles driven in town
(4) Miles driven with passenger

d. Other independent variables

(1) Weather conditions
(2) Roadway conditions
(3) Experimental variables
    (a) Alcohol
    (b) Drugs
    (c) Fatigue
(4) etc.

APPENDIX G

SAMPLES FROM MANUAL OF OPERATION

*Prepared by North Carolina Driver License Examiners, J. Day, J. Mangum, D. McIntyre, S. Parker.

INSTRUMENTED VEHICLE MANUAL

CHAPTER I. History of Instrumented Vehicle

CHAPTER II. Automotive

A. Maintenance

1. Source
2. Oil and Lubrication
3. Gas
4. Tires
5. Water and Cooling System
6. Air Cleaner
7. Spark Plugs and Tune-Ups
8. Motor Vehicle Inspection Law
9. Battery
10. Wash and Wax
11. Lights and Horn
12. Air Conditioner
13. Windshield Wipers
14. Exhaust System

B. Accessories

1. Fire Extinguisher
2. Foot Brake on Passenger Side
3. Tire Gauge
4. Tire Chains
5. Flares
6. First-Aid Kit
7. Warranty Card
8. Jumper Cables
9. Flashlight
10. Porta-Mirror

C. Security

1. Storage of Vehicles
2. Emergency Procedures
3. Credit Cards and Registration Card
4. Gas Ticket Book

CHAPTER III. Research Equipment

A. Description

B. Operating Instructions

1. Counters
2. Medical Monitor
3. Tape Recorder
4. Event Console
5. Operational Sequence

CHAPTER IV. Testing

A. Supplies

B. Procedure Relating to Subject or Applicant

CHAPTER V. Records

A. Log

B. Completed Data Forms

C. Record Keeping

D. Security of Records

E. Forms