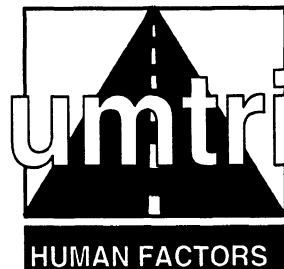Technical Report UMTRI-95-2   May, 1995

Calibration and Baseline Driving Data for the UMTRI Driver Interface Research Vehicle

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HUMAN FACTORS

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This report describes an experiment to determine the measurement errors and typical data associated with driving an instrumented research vehicle (1991 Honda Accord Station wagon). The vehicle is outfitted with sensors for headway, lateral position, speed, steering wheel angle, and throttle position. Video equipment records what the driver does and the forward scene. Three sets of tests were conducted for each type of measurement: static, dynamic, and driver in the loop. For example, for headway, these measurements would correspond to the mean and standard deviation of the headway when the car is parked, when one vehicle follows another (both with cruise control set), and when a driver follows a lead vehicle (with only the cruise control of the lead vehicle set).

The standard deviation of the steering wheel angle was 0.8 ssu (steering signal unit) when held statically, 1.1 and 1.3 ssu when the vehicle was driven (and the wheel was held rigidly and loosely), and 1.5 ssu when the driver attempted to minimize lane variance. When the wheel was held rigidly to minimize lane variance, vehicle drift led to a lane variance of 0.5 ft. When the lane standard deviation was minimized by drivers, it was 0.2 ft. When the vehicle was static, the lane width has a standard deviation of 0.0 ft. With the cruise control operating, speed was sinusoidal (1.1 mi/hr amplitude, 15 sec cycle). Under driver control when conditions were optimal, the standard deviation of speed was 1.0 mi/hr.

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PREFACE

This report is one of a series supported by the Road Commission of Oakland County, Michigan and the Federal Highway Administration as part of the FAST-TRAC (Faster and Safer Travel through Traffic Routing and Advanced Controls) Project. This operational field test combines the SCATS (Sydney Coordinated Automatic Traffic Control System) equipment and software, the Autoscope video detection system, and the ALI-SCOUT (Autofahrer Leit und Information System Scout) dynamic route guidance system. The goals of this effort are to improve traffic flow and reduce traffic accidents in Oakland County and the surrounding area.

ALI-SCOUT is a second generation product developed by Siemens that provides real-time, turn-by-turn guidance to drivers who have units installed in their vehicles. ALI-SCOUT vehicles communicate with infrared roadside beacons, sending travel times to the traffic control center, and receiving sequential routing instructions from the center.

An important part of the FAST-TRAC project involves evaluating the safety and ease of use of an in-vehicle guidance system. For that evaluation to be conducted, it is necessary to measure driver and vehicle performance when the equipment is being used, and to have baseline data when the system is not being used. That baseline data serve as the basis for identifying where practical and statistically significant differences occur and should include information on what is normal driving behavior, and how sensitive and consistent the measurements are.

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INTRODUCTION

Within the last few years there has been a significant effort to improve transportation by expanding the use of computer and communications technology. That effort has gone under the banners of Intelligent Transportation Systems (ITS) and Intelligent Vehicle-Highway Systems (IVHS) in the U.S., Advanced Transport Telematics (ATT) in Europe, and other names as well. Work relating to this has been funded by the DRIVE and PROMETHEUS program in Europe, and the RACS, AMTICS, VICS, and SSV programs in Japan, to name a few. In spite of the variety of names, these efforts share common goals--to improve the safety and operation efficiency of transportation, and to make getting there more pleasurable. A particular focus has been on driving and traffic congestion.

An important consideration in the introduction of these new systems, especially driver information systems, is that they should be safe and easy to use while driving. Assessments of such can be examined using surveys, laboratory experiments, and driving simulators. However, such systems must ultimately be evaluated on the road by a representative sample of drivers. These evaluations include both large scale field studies and detailed analyses in specially instrumented test vehicles.

The development of such test vehicles is extremely expensive. The instrumentation is complex and highly specialized, and talented human factors personnel are required to make judicious use of the equipment and analyze the vast amount of data collected. At the present time, the number of such vehicles is limited, probably less than 20 in the world.

The vehicle utilized for this project is by no means the first instrumented vehicle. Following is a description of some vehicles referred to in the literature that have been developed to provide an indication of the measurements of interest and the potential applications. Vehicles not described in the open literature have been omitted from this review. In contrast to the information reported here, data on baseline performance and vehicle sensor sensitivity in situ has not been reported in the literature (though sensor specifications have been).

Examples of First Generation Systems

One of the earliest instrumented vehicles was a 1970 Chrysler Imperial equipped by the Federal Highway Administration (FHWA) for studies related to in-vehicle signing and radio messages (Leifer, 1976). Equipment in this large four-door sedan allowed the measurement of speed, distance from a start point, response time to slides, steering wheel position, accelerator position, steering wheel reversals, accelerator reversals, brake applications, event codes, and time from the beginning of a test run. Data were recorded on magnetic tape. Film cameras recorded the forward and rearward scenes. Stimuli (slides of signs) were presented by a projector in the back seat aimed at a projection surface near the driver's sun visor. An overview of the research issues explored (e.g., sign design) appears in Mast, Ballas, and Peters (1976).

As a follow-up to this effort, Systems Technology developed a more sophisticated vehicle (Driver Performance Measurement and Analysis System-DPMAS) for the National Highway Traffic Safety Administration (NHTSA). The vehicle was developed for studies of driver training and licensing, and studies of abnormal behavior as induced by alcohol drugs, fatigue, and stress (McRuer, Peters, Ringland, Allen, Blauvelt, and Weir, 1974). The test vehicle, a four-door 1974 Chevrolet Impala sedan, was outfitted with an extensive set of sensors. Measures included steering wheel position and rate, throttle pedal position, brake line pressure, steer angle, heading angle, path angle, slide slip angle, vehicle attitude (angle and rate for pitch, roll, and yaw), lateral, longitudinal and vertical acceleration, lane position, the velocity of each of the four wheels, speed, experimenter's brake status, various steering system measures, multiple channel EEG and EMG readings, GSR, heart rate, and the status of various controls and displays (turn signal, brake light, radio on/off, wiper, horn, oil pressure, headlights) (Klein, Allen, and Peters, 1976). Measures were recorded by a digital tape recorder. Unique features of the system include the introduction of video cameras for recording the forward and rearward scenes, a roof-mounted lane tracker, variable geometry steering (modifiable by the experimenter), and the physiological recording system. The video record was a split screen image, with the top half showing the forward scene (with superimposed numerical data), and the bottom half split in two. The left half showed the driver's eyes (recorded by a camera aimed at the inside rear-view mirror). The right half showed the rear view.

Another vehicle worthy of note, used at the Lulea University of Technology in Sweden, was based on a 1971 Volvo Express station wagon (Helander and Hagvall, 1976). The vehicle included sensors for monitoring physiological variables (GSR, heart rate, EMG), steering wheel angle, brake press, triaxial accelerations, speed, and distance traveled. A keyboard was provided for coding traffic events. As with DPMAS, the data were stored on digital tape. Cameras for recording the road scene or in-vehicle activity are not described.

Sewell and Perratt (1975a,b) describe an instrumentation system installed in a 1970s model Mercury Marquis sedan used for headlighting studies. Sensors were provided for recording steering wheel angle, brake application, accelerator position, yaw angle, driver heart rate, various switch closures, and illumination level. Unique to this vehicle was a system for tracking the position of the test vehicle relative to an oncoming vehicle, and equipment used for headlight glare evaluation experiments. Data were stored on a seven-track reel-to-reel tape recorder.

Also described in the literature are vehicles developed for studies of alcohol-impaired drivers (Damkot, Geller, and Whitemore, 1977) and vehicle handling characteristics (Good, Dorey, and Joubert, 1982). Instrumentation of these vehicles was less extensive than for some of those previously described.

Examples of Second Generation Systems

Second generation systems were developed based on experience gained from constructing and using first generation systems. An example of one of the more interesting contemporary systems is described by Allen, Hogue, Rosenthal, and Parseghian (1989), a system used for fuel economy tests. It consists of a commercial

laptop computer with an open slot (for an input/output card), a signal conditioner, and external sensors (for fuel flow, speed and distance traveled, wind velocity and direction). A modified version of that system was used for studies of off-road vehicles. The off-road vehicle application is demanding because of the limited space and power available, and the unfavorable environmental conditions (heat, dust, vibration). For that application, sensors were provided for lateral and longitudinal acceleration, yaw rate, and steering wheel angle. The software was written in QuickBASIC, a well known application.

Van der Horst and Godthelp (1989) describe the Instrumented Car for Road User Studies (ICARUS), a well known test vehicle developed by TNO. This was one of the first contemporary vehicles designed for evaluating in-vehicle information systems. Sensors were provided for measuring steering wheel angle, pedal position, yaw velocity, triaxial acceleration, speed, and lateral position. Because of technological limitations, few prior vehicles equipped with lane tracking sensors performed reliably. Also fitted in the vehicle was an electrouminescent display and keyboard (for exploring driver interface concepts), liquid-crystal occlusion spectacles for the driver to wear (to explore driver eye movement strategies), and sensors for heart rate, respiration rate, GSR, and EEG. Data were recorded by an IBM AT computer.

In a subsequent effort, TNO instrumented a small van (Dodge RAM) using similar instrumentation. That vehicle, known as Instrumeted Car for Computer Assisted Driving (ICACAD), could be controlled either partially or completely via external hardware. Thus, studies of cooperative driving (relating to intelligent gas pedal or complete external headway control) could be readily conducted.

The focus of these vehicle instrumentation efforts has clearly been on cars, with one exception (King, Siegmund, and Montgomery, 1994) which describes instrumentation of a heavy truck. The instrumented truck was used to examine driver fatigue on a test track in a vehicle following task. Sensors were provided for vehicle speed, steering wheel angle and angular velocity, response time to hood-mounted lights, EEG, heart rate, lane position, and following distance. Also recorded were subjective assessments of driver fatigue. The instrumentation was fitted inside a Freightliner three-axle, conventional tractor with an integral sleeper. In contrast to instrumented cars, speed was measured using a fifth wheel (not the speedometer cable output) and position was obtained from a GPS (global positioning system) satellite data. Three personal computers were used to collect the data. Fatigue judgments were made by an experimenter in the sleeper who watched a monitor displaying the output from a camera aimed at the driver's face.

Thus, the trends in the literature were from analog to digital to computer recording of data, and from film to video for recording the forward scene. Common measurements included speed and steering wheel angle, along with driver physiological measures in many cases. However, there were variations in the measures collected with differences being due to the research topic (handling, effects of alcohol, in-vehicle information systems, etc.).

The UMTRI Driver Interface Research Vehicle

Based on knowledge gained from the literature, the UMTRI Driver Interface Research Vehicle (Sweet and Green, 1993) was developed for on-the-road evaluations of driver information systems, in particular those for navigation, traffic information, and related applications. It has also been used for evaluations of cellular phones.

The test vehicle is a 1991 Honda Accord station wagon. The vehicle has sensors for all major driver inputs to the vehicle (steering wheel angle, throttle and brake position, turn signal, cruise), vehicle responses (speed, lateral position), and has cameras for recording the forward scene and driver. All data are recorded by a digital computer. The vehicle also has been outfitted with a navigation system, a Macintosh computer, and various liquid crystal displays (LCD) for presenting information, and real and simulated cellular phones. The vehicle is described in much greater detail in the test plan section of this report.

The vehicle has been used for several experiments. In the first (Hoekstra, Williams, Green, and Paelke, 1992), drivers were presented with information on two alternative routes, four different ways: text describing the traffic, a color coded skeleton map showing the two routes, or video of the traffic in two formats. In the static condition, drivers were shown a single video frame of traffic on the route taken from a roadside camera. In the dynamic condition, they were shown a short clip. In each case, the two alternative routes were shown in succession while driving on an expressway, in response to which a driver pressed a button indicating the preferred route (A or B). The video clips were not live scenes, but rather segments presented from an in-vehicle computer-controlled VCR made to appear as if they were live.

Drivers had more problems with the video formats than the audio formats, taking longer to select a route, being less likely to select the optimum choice, taking more time to look at the in-vehicle display, and not rating the video formats as highly.

In the second major study drivers followed a 19-turn, 30-minute route as directed by various versions of a route guidance system (Green, Williams, Hoekstra, George, and Wen, 1993). Three versions were examined: voice-based, instrumented panel-based turn-by-turn, and a head-up display (HUD) presentation of the instrument panel based interface. In addition, during the trip drivers used a traffic information system, a vehicle monitoring system, and a hazard warning system. All systems were simulated using SuperCard programs running on the Macintosh computer.

In the first portion of the study, pairs of drivers followed the test route while discussing the various interfaces provided. This approach provided insight into the logic drivers used to understand the interfaces provided. It was apparent from driver comments and behavior, that these interfaces were safe enough to be tested by single drivers (as opposed to pairs).

Subsequently, in the next experiment, individual drivers were tested. Dependent measures examined included the mean and standard deviation of speed, the standard deviation of lane position, the standard deviation of steering wheel angle, the number

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of fixations to the in-vehicle displays, the number of turn errors, and various subjective ratings. Differences between the interfaces were small.

In a validation experiment, an extended version of the same route was used to provide additional baseline driving data (Green, Hoekstra, and Williams, 1993). In this experiment only the route guidance system and cellular phone were used. The results were consistent with the previous experiment.

Summary

The literature contains fairly detailed information on recording systems, the parameters measured, and the types of sensors used. In addition, there is a reasonable number of examples of studies conducted using these vehicles. In the case of the research described here, those examples were complemented by hands-on experience with a test vehicle. However, missing from the literature is information on how consistent measurements from such vehicles are in actual use (not sensor specifications), and comprehensive normative data on driver behavior. Such information is critical if differences from normal driving behavior (due to new information systems, fatigue, alcohol, enhanced steering, braking, and handling, etc.) are to be examined.

Research Issues

These shortcomings (lack of information of measurment consistency, lack of normative driving data, etc.), along with needs specific to the FAST TRAC project, led to the research described in this report. To prepare for the FAST-TRAC project, several modifications were made to the Driver Interface Research Vehicle (briefly described earlier). Major additions included a headway sensor, a second lane tracker (so the distance from two lane markings could be determined), and a quad splitter to consolidate the video information. Modifications were made to the speed sensor (to eliminate signal drop outs), and other enhancements (e.g., padding the equipment rack, adding a cellular phone) were made as well. A NAC model V eye camera, used in the previous studies has been removed and will eventually be replaced.

Prior to collecting additional driver performance data, it was deemed necessary to collect information on sensor signal quality and baseline driver performance. Ideally, this information should have been collected when the vehicle was first developed.

Sensor and system measurements can be thought of as being of three types (1) measurements with a stationary vehicle, (2) measurements with a moving vehicle under "automatic" control (indicative of the best the vehicle can do) and (3) in-the-loop measurements under ideal conditions with the experienced drivers (indicative of the best a driver can do). In this experiment, ideal conditions are flat roads with no curves, clear weather with minimal wind, and little or no traffic. Three general issues are addressed:

1. How accurate are the measurements of speed, steering wheel angle, lateral position, and headway when the vehicle is stationary?

2. How accurate are those measurements when the vehicle is operated using the cruise control?

3. What is the best performance one can expect from drivers when they are told to focus on either minimizing steering wheel motion, speed variance, lateral variance, or headway variance?

These three issues can be expanded into the following more specific questions.

1. What is the relationship between the computer-reported steering wheel angle and turn radius?
2. How accurate are the static measurements of speed, steering wheel angle, lateral position, and headway?
3. What is relationship between the speeds reported by the computer, the speedometer, and speed as computed from timed runs between mile posts?
4. When the car's speed is controlled by the cruise unit, how variable is the speed?
5. When a car is driven with no steering input or the steering wheel rigidly held in place, how much does the vehicle drift?
6. When a car using cruise control follows another car using cruise control, what is the standard deviation of headway? (This represents minimum headway variability likely to occur.)
7. When a driver is told to focus on staying in the center of the lane, or drive at a fixed speed, or keep a constant headway, how well do they do? (This is the best a driver can do.)

To address these issues, various tests were carried out in parking lots and on local expressways.

TEST PLAN

Driver Interface Research Vehicle (Test Vehicle)

Most of the equipment in the research vehicle falls into one of three basic categories: video recording, engineering data collection, and power supplies.

The video recording system consists of two bullet (lipstick) cameras (one to record the forward scene mounted below the inside rear view mirror, a second aimed at the driver and mounted on the A-pillar), and two small cameras located in the outside mirrors to record the lane markings on either side of the vehicle (lane trackers). Camera outputs are combined, along with a summary of the data collected by the computer (described below) by a quad splitter, displayed on a monitor, and recorded on a VCR. The two lane tracker images are combined by a two-image splitter and fill one quadrant of the quad splitter image. Figure 1 shows a typical quad-screen image.

driver   forward scene

left lane   right lane   engineering data
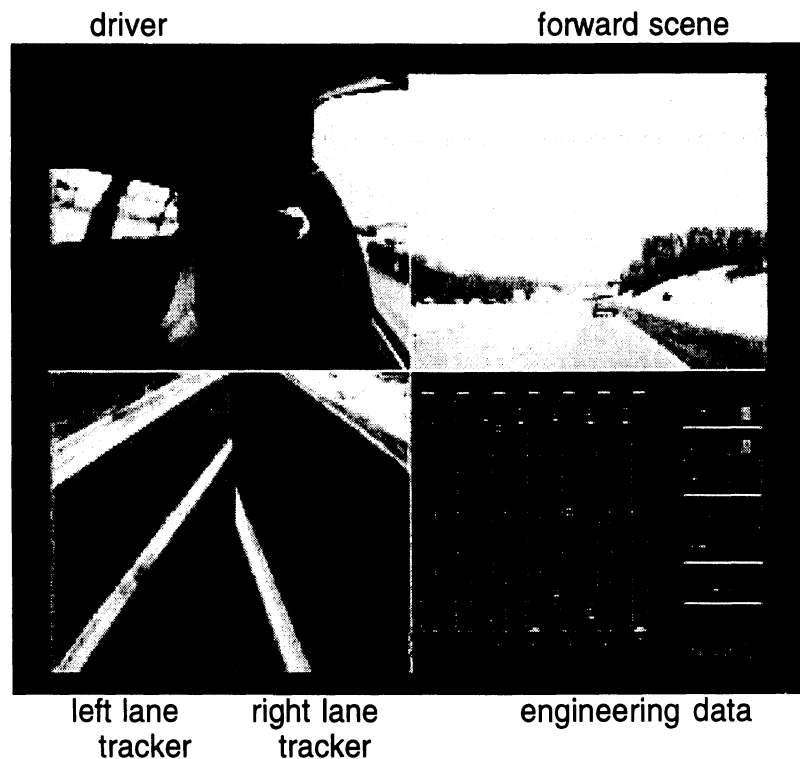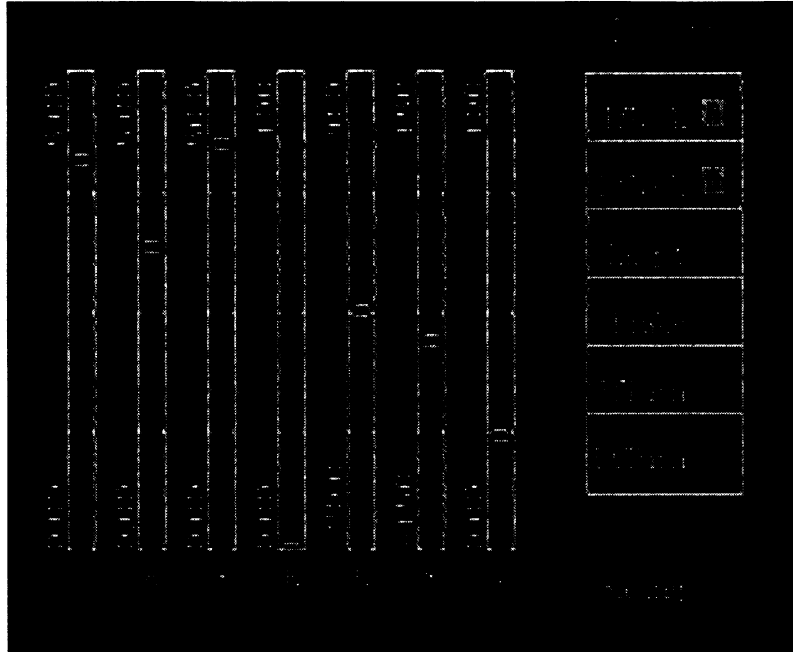tracker   tracker

Figure 1. Typical Quad-Screen Image.

Sound is picked up by two miniature lavolier microphones, one mounted on the A-pillar, a second mounted on the inside rear view mirror. An audio mixer combines the two microphone outputs for recording on one of the VCR's audio channels.

Engineering data is collected by a 486 computer via a custom-made signal conditioner (both located in the cargo section of the car). Sensors include a potentiometer mounted below the steering wheel (to measure steering wheel angle), headway sensor mounted to the front bumper, and engine computer located under the passenger's feet to collect speed, throttle, and brake signals. (See Figure 2.) Lane

position is determined in real time by the 486 by processing video images from the lane trackers. The 486 gets the majority of its data from the custom built signal conditioner that receives the signals from both the engine controller chip and the steering column sensor. The data are stored on an external hard drive and then copied to a Bernoulli drive for analysis.

The capital letters L,R,S,R,R,S,T at the bottom of the screen correspond to the signals: left lane tracker, right lane tracker, speed, range, range rate, steering, throttle.

Figure 2. Enlarged view of the Engineering Data Quadrant

The data-collection and video equipment can be either powered by the car, or when stationary and being checked out, by a 110 volt AC wall outlet source. During on-road tests, a 400 watt AC power converter connected to the car's electrical system supplements the 12 volt supply drawn from the car's battery. The stock Honda Accord alternator is used and there are no supplemental batteries to power the equipment. Figure 3 shows most of the engineering data equipment and the power supplies in the rear of the test vehicle. In many experiments, a Macintosh computer (running SuperCard) is also installed to present driver interfaces on one or more LCDs mounted on the instrument panel.
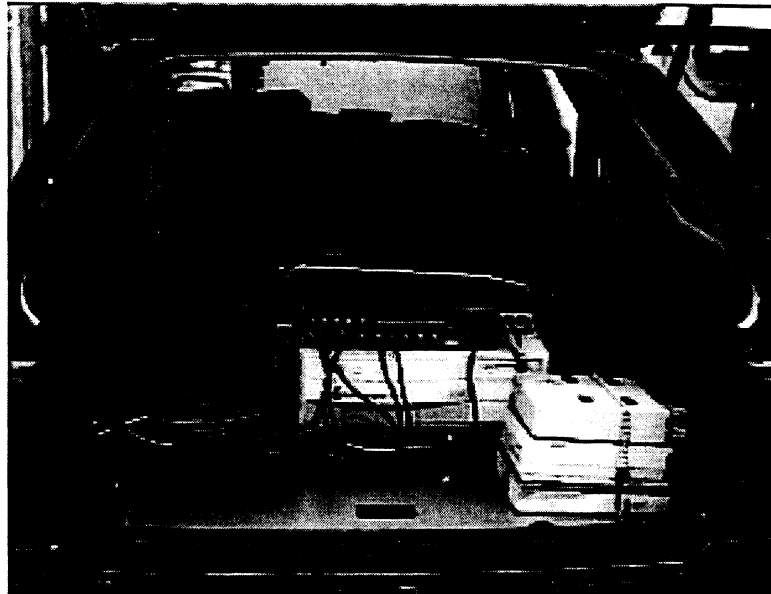
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Figure 3. Data Collection Equipment and Power Supplies

All equipment is operated by an experimenter seated in the right rear passenger seat. Using the video display showing the quad splitter output (Figure 1), the experimenter monitors the camera output, making adjustments as necessary, as well as checking the proper operation of all engineering data sensors. A keyboard is in the equipment rack next to the experimenter (and behind the driver). This rack also contains all the camera controls, a VCR, audio mixer, and a video display. Figure 4 shows the arrangement of most of the equipment operated by the experimenter. Not shown is the quad splitter (behind the driver's seat) and the cellular phone (used in emergencies and stored under the equipment rack). Figure 5 shows a plan view of the test vehicle and the model numbers of all equipment in the vehicle.

Figure 4. Some of the Equipment Operated by the Experimenter.

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Driver Interface Research Vehicle
1991 Honda Accord LX Wagon

Headway sensor — Leica Odin II

Transmission controller

Electronic Control Unit (ECU)

Right lane tracking camera — Phillips 56475

Ali-Scout navigation unit

Ali-Scout beacon transmitter

Scene camera — Panasonic GP-KS152 with 1:1.4 3mm lens

Left lane tracking camera — Phillips 56475

Driver camera — Panasonic GP-KS152 with 1:1.4 3mm lens

PC compatible keyboard

Color video monitor — Panasonic BT-S901Y

(2) Camera controllers — Panasonic GP-KS152

Super VHS VCR — Panasonic AG-5700

Data collection computer — Gateway 2000 33MHz 486 with 4 MBytes RAM, National Instruments AT MIO-16 and PC DIO-24 boards, Cortex-I video frame grabber, 16 bit SCSI card, and Ergo LCD display card

Microphone mixer — Shure M267

Quad splitter — Panasonic WJ-450

Splitter/inserter — American Dynamics 1470A

Custom signal conditioning module

400 Watt inverter — PowerStar model UPG 400, 12V power supply & +15/-15V power supply

Video converter — ADS VGA->TV Elite

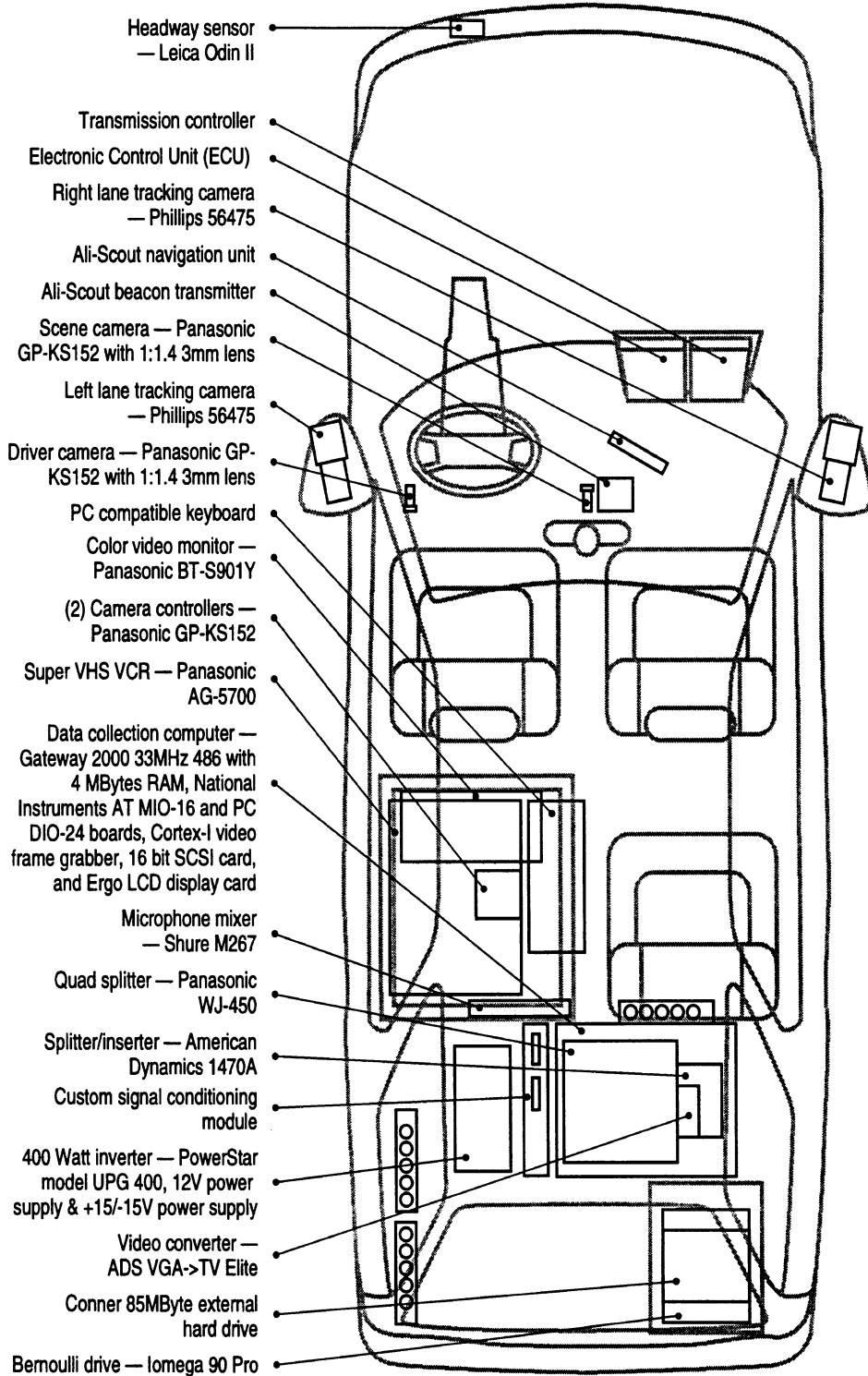Conner 85MByte external hard drive

Bernoulli drive — Iomega 90 Pro

Figure 5. Equipment installed in the test vehicle.

Test Activities and Their Sequence

Measurements were collected for three conditions: static (collected in a parking lot with the vehicle not moving), dynamic (collected on road in situations in which driver input was eliminated or minimized), and driver in the loop (collected on road in situations in which both within and between driver differences were of interest). Dependent measures of interest included speed, lateral position, steering wheel angle, and headway. Table 1 summarizes the measurements made with additional details appearing later in this section.

Table 1. Overview of Measurements of Interest.

	Speed	Lateral Position	Steering	Headway
Static	not applicable (must be moving to calibrate speed)	How well can the lateral position be measured under ideal conditions? Task: Calibrate using special calibration targets (simulated lines) in parking lot.	What are the values reported by the computer? Task: Turn steering wheel 90 deg left and right while car is stopped.	How close is the value reported by the computer to the actual value? How stable is the reported value? Task: Point parked car towards stationary reflective target.
Dynamic	How well do the data logging system and timed miles agree? Task: Drive with the cruise control set.	How much does the car normally drift? Task: Drive straight with the wheel held loosely (no input) and rigidly (no movement allowed).	What is the variability of the measured angle (by the software)? Task: Drive straight with the wheel held loosely (no input) and rigidly (no movement allowed).	What is the headway variability due to the car? Task: With the cruise on, follow a lead vehicle (with cruise on) being driven at the same speed.
With Driver in the Loop	What is the mean speed indicated by the logging software and what is the speed variance? Task: Concentrate on driving at a fixed speed (no traffic).	What are the mean and standard deviation of lateral position? Task: Concentrate on driving in the center of a lane (no traffic).	What is the standard deviation of steering wheel angle? Task: Keep the vehicle in a lane with a minimum of large wheel movements.	What is the headway variability due to the driver? Task: Follow a car (whose speed is cruise controlled) at a constant distance. (Drivers ignore speed and lane position.)

Part 1 - Static Calibration of Lateral Position, Steering, and Headway

All of the static calibration tests were conducted on a large, flat, open parking lot or similar paved surface. In these experiments, the parking lot of a local movie theater was used in addition to UMTRI's garage and parking lot. The purpose of the static

experiments was to calibrate the car's equipment. Therefore no subjects were used. Two experimenters conducted the tests.

To obtain lateral position data, the experimenters created mock lanes. Lane markings were made from long strips of 3.75 in wide white sanitary tissue paper, taped along either edge to the cement floor of the UMTRI garage with black electrical tape (to improve contrast). The test vehicle was parked 2 ft from the outer edge of the car to the inner edge of the lane on both sides. The experimenters then collected data for approximately 20 sec. The mean and variance of the lateral distance given by the lane trackers was then calculated.

For the static steering calibration, the test vehicle was parked in the UMTRI parking lot with the tires pointed straight ahead. One experimenter turned the steering wheel 90 deg to the right for 20 sec, then returned the steering wheel to the straight ahead position. The process was then repeated, but the steering wheel was turned 90 deg to the left, rather than the right. The mean and variance of the steering angle were then determined.

The static headway calibration was conducted in a large, flat parking lot where a rectangular target (4 ft wide by 2 ft high, target bottom 17 in above the ground), with a 16.5 x 18 in square of encapsulated grade highway sign material, was placed at a series of distances directly in front of the test vehicle. The sensor recorded the headway to the nearest 1/10 m (3.3 ft) to the target for 20 sec. This process was repeated for every 10 m (33 ft) up to and including 80 m (262 ft). The mean and variance of the three second intervals recorded by the headway sensor were then calculated for each distance.

Part 2 - Dynamic Calibration of Speed, Lateral Position, and Steering

Dynamic calibrations concerned the behavior of the vehicle, independent of the driver, under steady state conditions. Tests were conducted on sections of M-14, a four-lane, limited-access road, north and east of Ann Arbor, Michigan. Two short and two long sections (all straight and level) provided those steady state conditions and were used for data collection. (See Figure 7). Tests were conducted when winds were light and traffic was minimal (between 10 AM and 4 PM). Since these calibrations emphasized the vehicle, not the drivers, there were no subjects per se. The experimenters drove the test vehicle.

North

1.9 miles

1.5 miles

0.4 miles

1.6 miles

14

14

14

14

14

Beck Rd.
Exit 18

Gotfredson Rd.
Exit 15

Ford Rd.
Exit 10

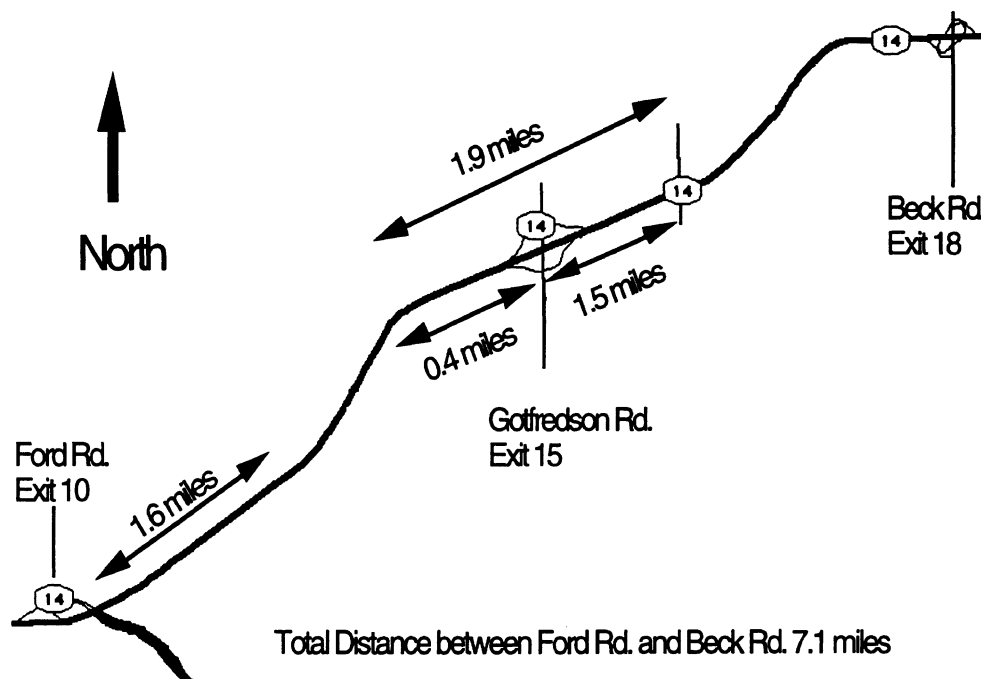Total Distance between Ford Rd. and Beck Rd. 7.1 miles

Figure 7. Sections of M-14 used for dynamic calibrations

Two speed calibrations were conducted on the two longer (five-mile) straight sections of M-14 (between Ford and Beck Rd. exits). During the first calibration sequence, one experimenter drove the car and another served as the experimenter. The driver set the cruise control at 55 mi/hr and the experimenter informed the driver when data collection began and when the test was completed. The speed signal was sampled at 10 Hz in all tests. This test was then repeated with the cruise control set at 65 mi/hr.

During the second calibration sequence the first experimenter drove the test vehicle, setting the cruise control at 55 mi/hr. The second experimenter held a stopwatch to time the distance driven. Once the car reached 55 mi/hr, the experimenter began timing when the car passed the next roadside mile marker. The experimenter recorded the time at each mile marker for five consecutive miles. This process was repeated twice. The driver then set the cruise control for 65 mi/hr and the entire test was conducted again.

Two experimenters were involved with the series of steering calibration tests. One experimenter drove the car at a fairly constant speed of 55 mi/hr, although this was not the main task of the test. The driver held the steering wheel loosely, with only enough force to keep the vehicle in the right lane of the highway. Data were collected on the two longer straight sections of M-14. The entire test was repeated with the driver holding the steering wheel rigidly (to damp out road-induced steering system vibration) with all other constraints being the same.

To evaluate the headway sensor, a lead vehicle (1991 Ford Taurus station wagon) was followed. The lead car was driven by an experimenter with the cruise control set at 55 mi/hr. The test vehicle (with its cruise control also set a 55 mi/hr) followed the lead vehicle, attempting to stay behind it.

Part 3 - Tests with Drivers in the Loop

Except for the turn radius tests, the driver in-the-loop tests were conducted on straight sections of M-14 (See Figure 7). The driver in-the-loop tests focus on the driver's abilities. Therefore subjects were used in these experiments. In this pilot effort, four licensed drivers, all employees of the Human Factors Division of UMTRI, participated. There were two men (23 and 24 years old) and two women (21 and 38).

Subjects were instructed to maintain a steady speed of 55 mi/hr in the right lane of a straight section of highway. The experimenter told the subject when to begin and when the data had stopped being recorded. The driver practiced on two shorter (1.6 mi) straight sections of M-14 and data were recorded on two longer (1.9 mi) sections of M-14. This test determined how well drivers can maintain a steady speed (55 mi/hr) under ideal conditions. The entire driver-in-the-loop calibration test was then repeated with a target speed of 65 mi/hr.

The lateral position calibration tests used the same four drivers as the speed calibration tests. Subject were instructed to drive the vehicle in the center of the right lane (an equal distance from either edge of the lane). Again, the experimenter told subjects when to begin and to stop. Subjects drove two practice sections and two test sections.

To determine how well drivers could follow a lead vehicle under optimal conditions, an experimenter drove a lead vehicle (1991 Taurus station wagon), setting its cruise control between 55 and 65 mi/hr. The subject, driving the instrumented vehicle, was instructed to drive a self-determined small distance behind the lead car and to maintain that distance until told to stop. This test was conducted on two straight sections of M-14. The same test was then repeated with the driver maintaining a self-determined large distance from the lead car.

Evaluation Addenda

Steering Signal vs. Turn Radius

To determine the relationship between steering wheel angle and turn radius, a subject drove at a constant speed around a circle in a movie theater parking lot. This test was conducted in the early morning hours to insure an empty area. A two-foot diameter lightpost marked the center of the circle. The circle's circumference was marked off by orange traffic cones. The subject was then told to drive clockwise around the cones, as close to the circumference as possible, at approximately 5 mi/hr, for at least 20 sec. Then the subject was told to drive the same path at approximately 15 mi/hr. The subject was then asked to repeat the process driving in the counterclockwise direction. Nine different radii were driven: 11.5, 16.5, 21.5, 26.5, 31.5, 37, 47, 57, and 77 ft. Note: the actual turn radii are these distances plus half the width of the car (approximately 3 ft more).

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Throttle Calibration Task

The purpose of this task was to examine the range of potential accelerator pedal values. This dynamic test was conducted twice on each of the same two straight sections of the M-14 highway (four times total). Each of four subjects pulled off of the road to the side of the highway, then waited for traffic to clear. When it was safe to do so, the driver pulled back onto the road pressing the gas pedal down at a constant rate until the pedal was to the floor of the car, thus taking the car from zero to full throttle.

RESULTS

Data Reduction

Most of the time spent analyzing the results was devoted to reducing the data, not computing test statistics. Engineering data were saved by the test vehicle computer as text files. The files were opened in Microsoft Word, edited to remove undesired sections, saved as text files, and then edited in Excel to remove unnecessary columns and clean up the speed signal. As part of the review process, plots of all variables were created to spot anomalies. Descriptive statistics were computed using Excel, Statview, and Systat. The steering, throttle, range and range rate signals are sampled at 30 Hz, while all other signals are sampled at 10 Hz. Due to the mismatch in sampling rates, signals sampled at 10 Hz will repeat a value twice before the signal is sampled again. All data sample figures in this report are of 1.6 min (1000 msec/sec x 60 sec/min x 1.6 min = 96,000 msec) samples consisting of 2880 data points (30 samples/sec x 60 sec/min x 1.6 min).

When driving at a steady 55 mi/hr (though this also occurs at other speeds), a wheel pulse signal from the Honda's Engine Controlling Unit is occasionally missed, causing the recorded speed to drop by 2 mi/hr and then return to the previous speed on the next sample. Below is the Excel formula used to "clean up" the speed signal. The process is iterative across columns until there are no significant drops in speed remaining. The C's represent columns in Excel. In the computation it looks at cells to the left and checks for a significant change in speed. If there is a drop then the previous speed column value is used to replace the "dropping" value. The formula also looks for a sudden increase in the speed signal, which translates into the end of the speed drop. This formula requires multiple applications as the drops can last up to 15 consecutive values. This requires that the data undergo at least 8 passes of the formula. Figure 8 shows raw speed data taken from a subject.

=IF((C2-C3)>1.4,C2,IF((C4-C3)>1.4,C4,C3))

Where:
C2= The cell one to the left and one higher of the current speed value.
C3= The cell one to the left of the current speed value.
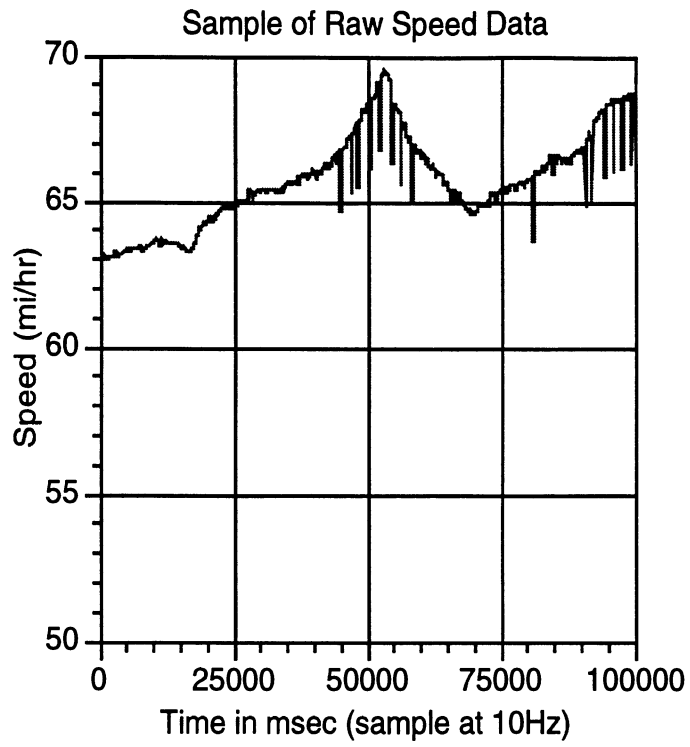C4= The cell one to the left and one lower of the current speed value

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Sample of Raw Speed Data

Figure 8. Raw Speed Data

Static Tests

With the car stationary, the lane trackers are highly accurate. (See Figure 9.) There is no fluctuation in reported lateral distance from the centerline of the car to either edge marking (recorded to the nearest 0.1 ft) or their total (the lane width).
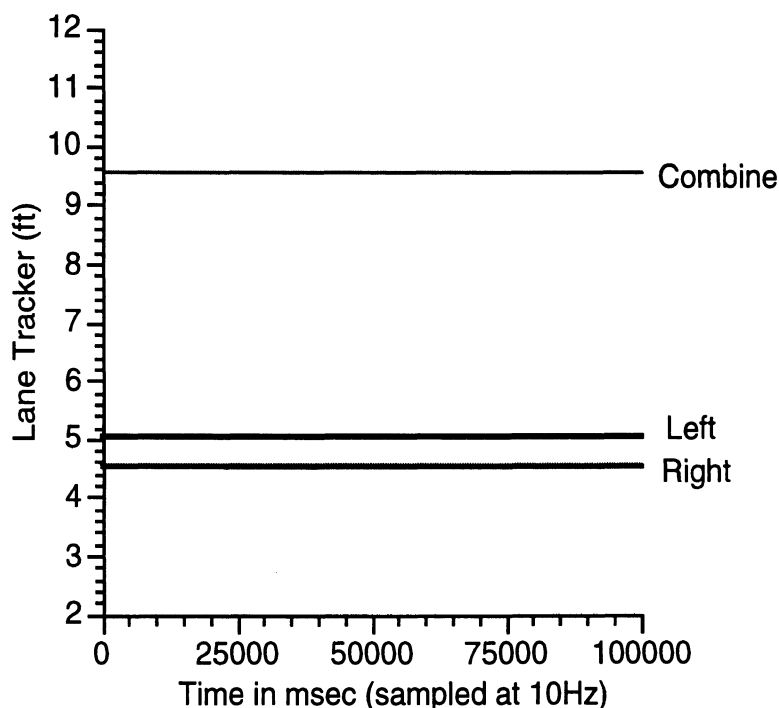

Figure 9. Static Test - Lane Tracker Outputs

The steering wheel signal has a range from -545.6 ssu (steering signal unit) to 525.2 ssu (3 turns from lock to lock) where the centered position is -24.5 ssu. (The center position was not zero because the steering wheel potentiometer was not aligned.) A 90 degree clockwise turn produces a signal value of 77.9 ssu. A 90 degree counter-clockwise turn produces a signal value of -104.4 ssu. Figure 10 shows the data from one trial sequence, three positions held for 20 sec by one driver. To maintain consistency with the figures showing other signals (all 1.6 min long) the same 20 sec sample is repeated five times on each figure. The signal can vary by as much as 5 ssu but the mean of the standard deviations for all three positions is about 0.8 ssu. Results from the static calibration tests are summarized in Table 2.
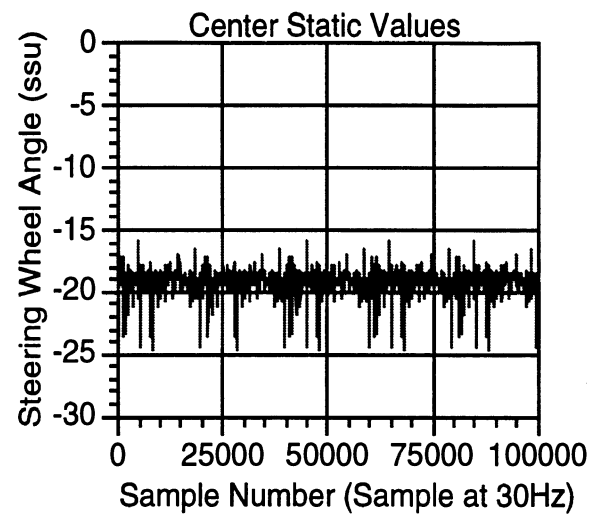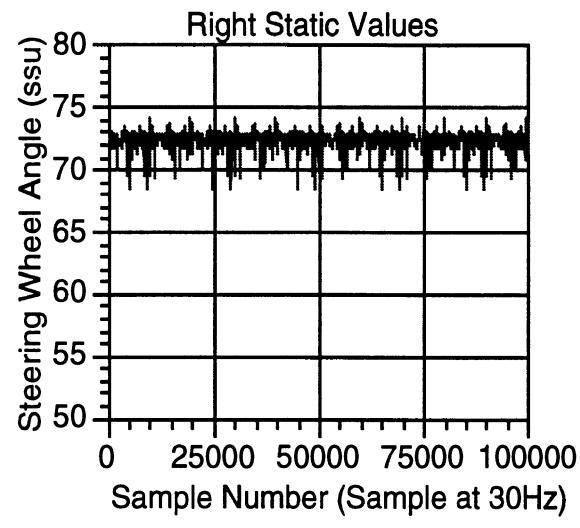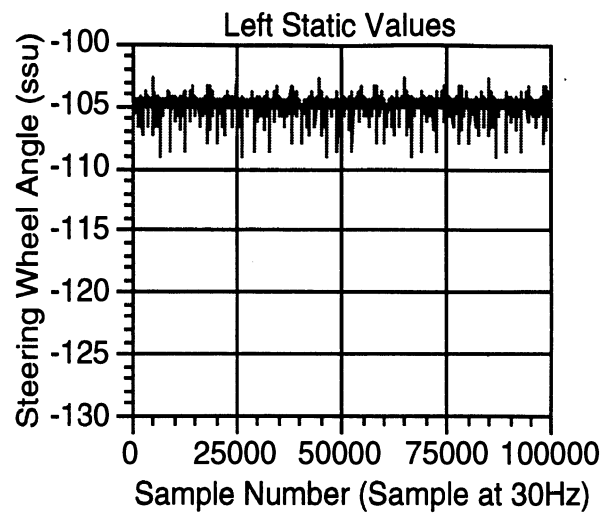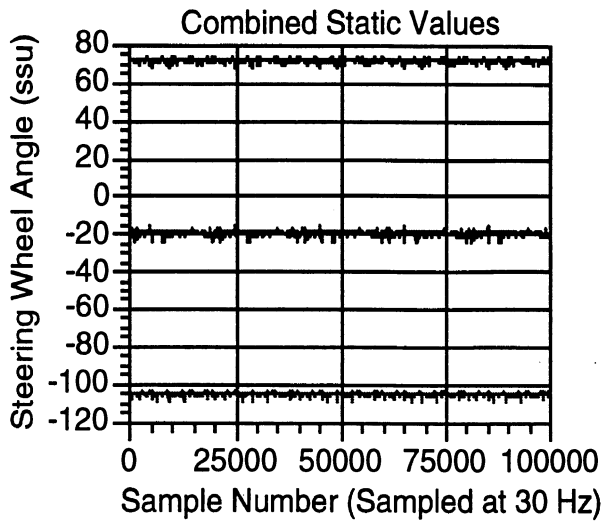
19

Figure 10. Static Steering Values

Table 2. Overview of Static Results

	Lateral Position		Steering	
Static Calibration	How well can the lateral position be measured under ideal conditions? Task: Calibrate using special calibration targets in parking lot.		What are the values reported by the computer? Task: Turn steering wheel 90 deg left and right, also to zero position (straight ahead) while the car is stopped.	
Results	left sensor right sensor	0 variation (to nearest 0.1 ft) 0 variation (to nearest 0.1 ft)	90 clockwise mean 90 clockwise std. dev.	77.9 ssu 1.0 ssu
			90 counter-clockwise mean 90 counter-clockwise std. dev. centered mean centered std. dev.	-104.4 ssu 0.7 ssu -19.1 ssu 0.7 ssu

Dynamic Tests

Figure 11 shows a sample of the cruise control data. When the cruise control is engaged the speed varies slightly (sinusoidal function with an amplitude of 1.1 mi/hr and a period of 15 sec).
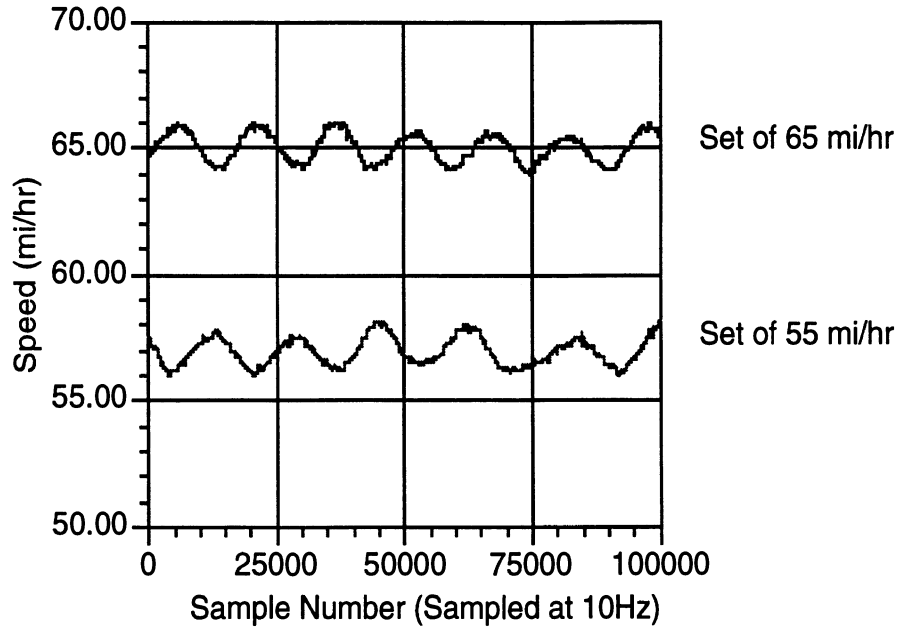

Figure 11. Cruise Control Speed.

As described in the procedure, the experimenters timed when the test vehicle passed mile markers while the cruise control was set. The results, along with the calculated speed according to the times are shown in Table 3.

Table 3. Summary of Timed Speed Test

Trial	Stopwatch Timing		Wheel Pulse speed (mi/hr)	Difference speed (mi/hr)
	Elapsed time (mm:ss.ss)	Calculated speed (mi/hr)		
55 mi/hr Trial 1	1:05.27	55.16	56.35	1.19
	2:10.55	55.15	56.28	1.14
	3:15.83	55.15	56.30	1.16
	4:20.86	55.36	56.25	0.89
	5:26.02	55.25	56.35	1.10
		55.21	**56.31**	**1.10**
55 mi/hr Trial 2	1:05.12	55.28	55.95	0.67
	2:10.93	54.70	55.80	1.10
	3:17.45	54.12	55.95	1.83
	4:22.21	55.59	56.75	1.16
	5:26.84	55.70	56.80	1.10
		55.08	**56.25**	**1.17**
65 mi/hr Trial 1	55.02	65.43	66.68	1.25
	1:49.80	65.72	66.63	0.91
	2:45.15	65.04	66.53	1.49
	3:40.21	65.38	66.59	1.20
	4:35.25	65.41	66.63	1.22
		65.40	**66.61**	**1.22**
65 mi/hr Trial 2	55.61	64.74	66.50	1.77
	1:50.70	65.45	66.67	1.21
	2:45.61	65.45	66.71	1.26
	3:39.08	67.33	66.46	-0.87
	4:34.48	64.98	66.62	1.64
		65.59	**66.59**	**1.00**
Overall difference between reported and timed speed				**1.12**

The timed speed and the speed signal agree to within 1.12 mi/hr (2 percent) with a standard deviation of less than 0.6 mi/hr. (See Figure 8.) The difference is quite small considering that the timed speed was collected manually with a stop watch. It should also be noted that the ground truth (distance between mile post markers) is only an estimate as the location of mile post markers can vary plus or minus 100 ft from the true position (depending upon the installing contractor (Kostyniuk, 1995). That alone is a 2 percent difference (100/5280). With an analog speedometer, it is easy for the driver to set the speed control incorrectly. This may account for the slightly high readings.

Figure 12 shows the relationship between right and left lateral positions, and the estimated lane width. The lane tracker's accuracy and consistency fall off once the vehicle is in motion. For the sample shown (Figure 12) the mean measured lane width (between the lane delineation centerlines) was 11.6 ft, slightly under the nominal 12-ft design width of the lane. This difference may be due to measurement error of the device or misapplication of the painted road markings. This is mostly irrespective of how tightly the steering wheel is held. The standard deviation was 0.5 ft (6 in). (See

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Figure 12.) The assumed error dropped from 0 percent to 3 percent while the standard deviation jumps from effectively zero to 0.5 ft.
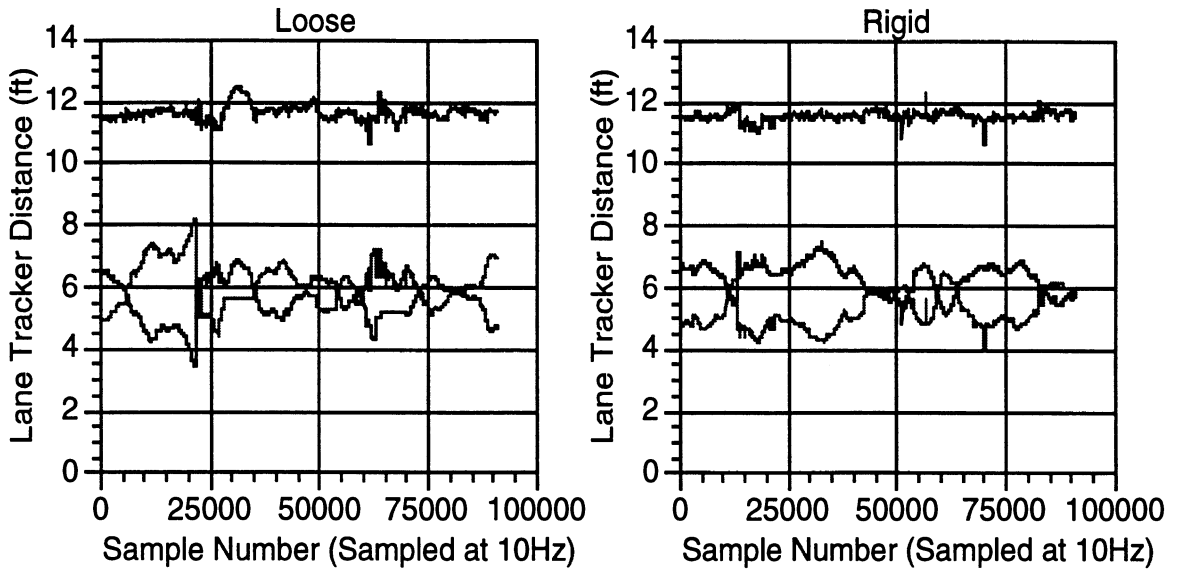

Figure 12. Loose and Rigid Lane Trackers

The steering test's two conditions, loose and rigid, yielded similar results. (See Figure 13). Both had a range of about 14 ssu. The standard deviation of the loose condition was 1.3 ssu as opposed to the rigid standard deviation of 1.1 ssu. In the static tests the standard deviation was 0.8 ssu, with motion and vibration assuming responsibility for the increased variation. Results from the dynamic calibration tests are shown in Table 3.
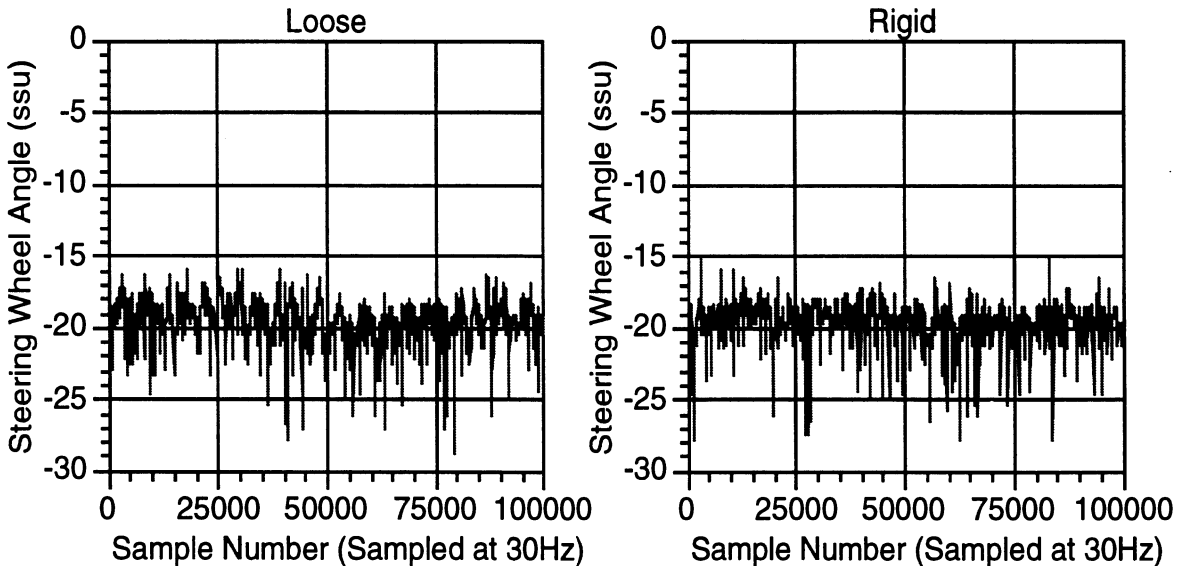
Figure 13. Loose and Rigid Steering

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Table 3. Overview Dynamic Results

	Speed		Lateral Position		Steering	
Dynamic	Task: Drive with the cruise control set. How well to the data logging system, and timed miles agree?		Task: Drive straight with the wheel held loosely (no input) and rigidly (no movement allowed).		Task: Drive straight with the wheel held loosely (no input) and rigidly (no movement allowed). How well do the actual and data logging system values agree?	
Results	55mi/hr mean acc 55mi/hr stdev acc	3% 0%	loose mean(ft) loose st. dev.(ft)	5.8 0.6	loose mean(ssu) loose st. dev.(ssu)	-19.1 1.3
	65mi/hr mean acc 65mi/hr stdev acc	1% 10%	rigid mean(ft) rigid st. dev.(ft)	5.8 0.5	rigid mean(ssu) rigid st. dev.(ssu)	-19.2 1.1

Driver-in-the-Loop Tests

When asked to drive at a steady speed of 55 mi/hr or 65 mi/hr, averaged across all eight trials (four people driving two sections two-miles long), drivers exceeded the desired speed by 2.2 mi/hr. (See Figures 14 and 15.) The overall standard deviation was 1.0 mi/hr with an average range, per driver, of 5 mi/hr. Although one driver had a peak as fast as 12 mi/hr over the desired speed, others slowed to 4 mi/hr below the desired speed. About 4 mi/hr of this peak can be explained by a high average speed as well as driver variation. Less than half of the variation can be accounted for by the system, the remaining variation is due to the driver.

To pinpoint the sources of variation in the mean and standard deviation of speed, ANOVA was used. The independent measures were requested speed, driver, and trial. For the mean speed, only one factor had a statistically significant effect, requested speed ($p<0.0001$). The p-values for driver and trial effects were 0.68 and 0.43 respectively. For the standard deviation of speed, none of the main effects (requested speed ($p=0.57$), Driver ($p=0.41$), or Trial ($p=0.60$)) were significant.
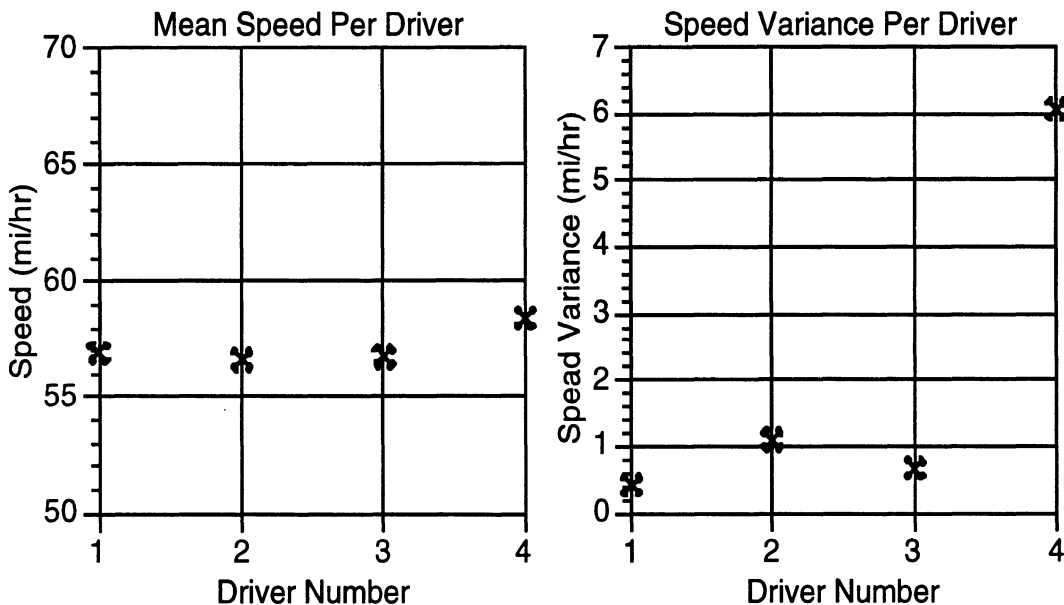

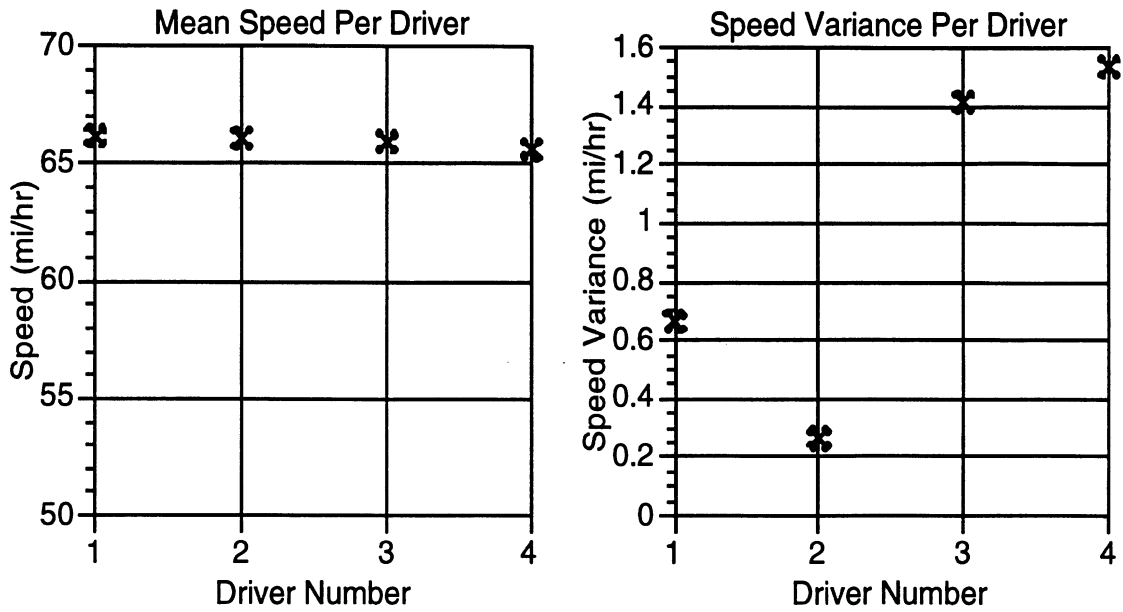Figure 14. Steady Speed Maintenance at 55 mi/hr

Figure 15. Steady Speed Maintenance at 65 mi/hr

When asked to drive in the center of the lane, drivers could maintain their position in the lane to within 0.42 ft (See Figures 16, 17, and 18.), although the range was as great as 2.5 ft. On the whole, drivers excel at this task. It should be noted that three of the trials had obvious outliers and were removed as the data were suspect. These trials included several situations in which the lane tracker locked on to the car's shadow (so the distance to one edge marking varied while the other remained fixed).
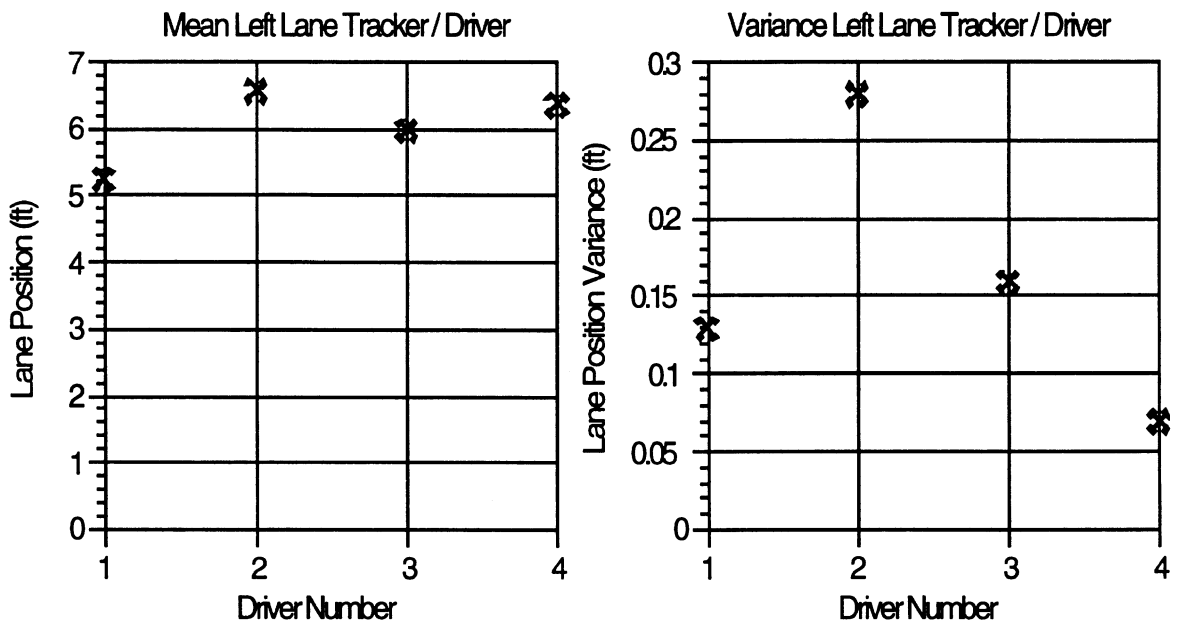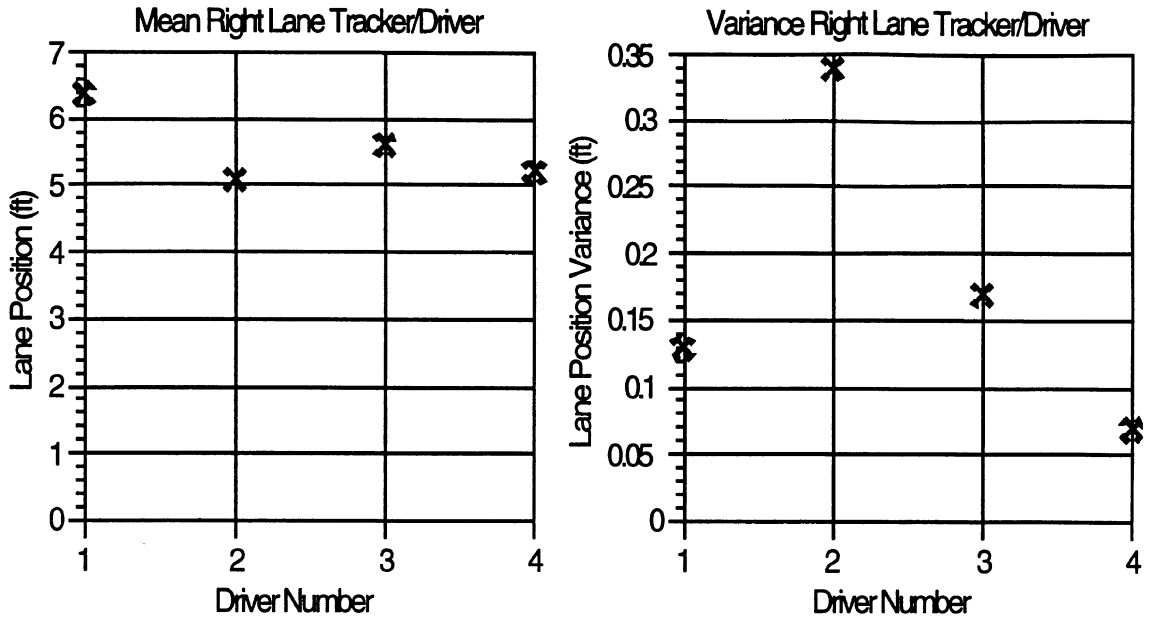

Figure 16. Left Lane Tracker Accuracy
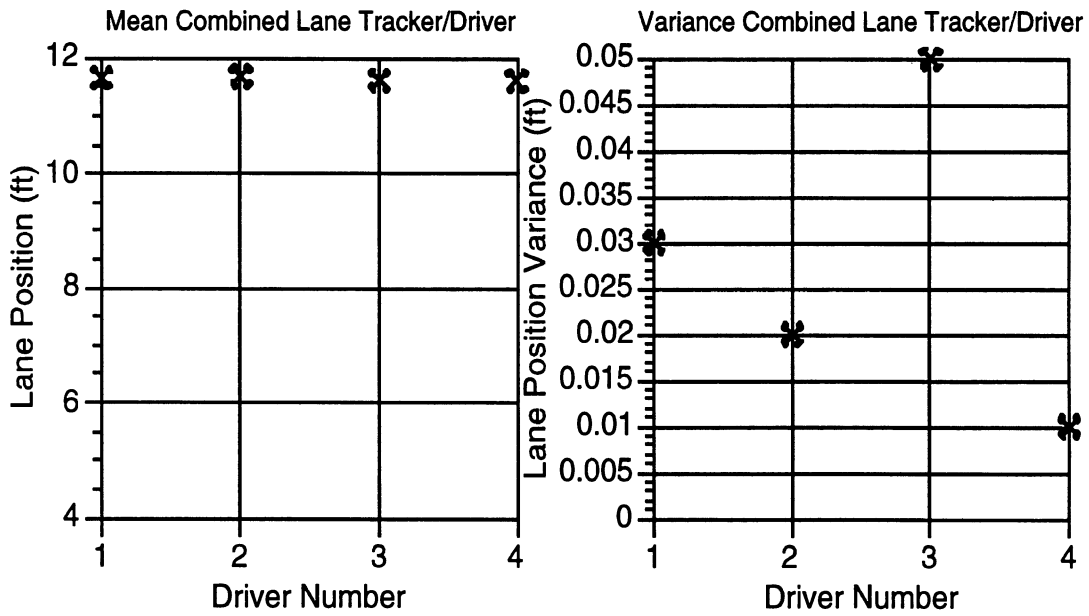
Figure 17. Right Lane Tracker Accuracy

Figure 18. Combined Lane Tracker Accuracy

The standard deviation of the steering signal when maintaining centered lane position was 1.5 ssu (see Figure 19.), which is only an increase of about 0.4 ssu over the standard deviation of the steering signal in the dynamic tasks. This is a fairly low level of noise considering the system has a standard deviation of 0.8 ssu. The range was as high as 20 ssu, but these were momentary corrections to ensure lane position, due to bumps, gusts of wind, and at least one sneeze.
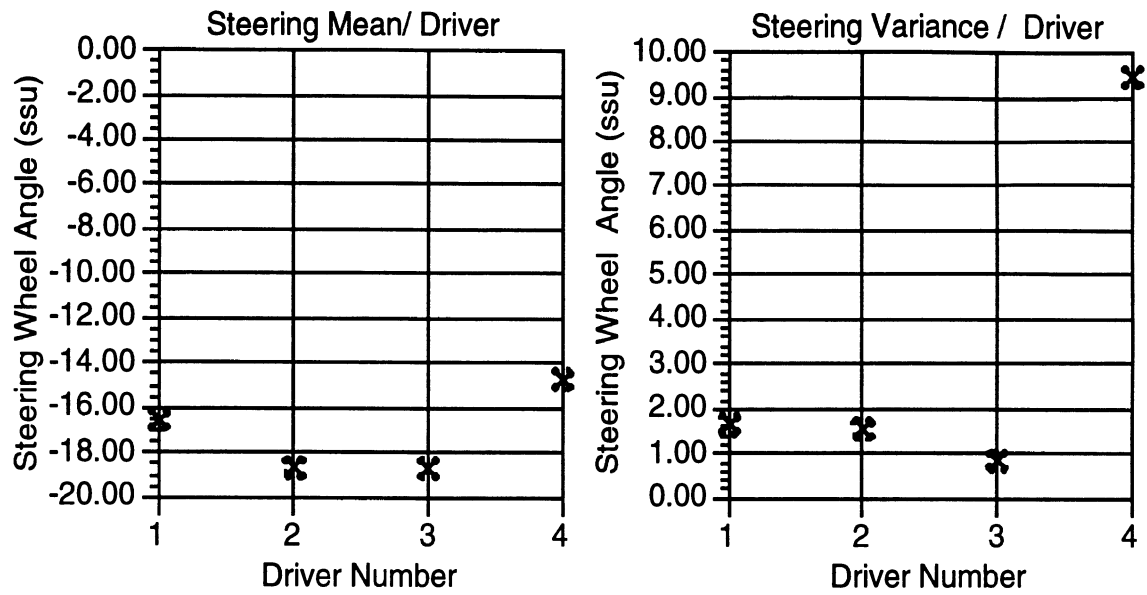
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Figure 19. Center Lane Steering Behavior Per Driver

A typical driver's behavior when attempting to maintain a centered position in the lane is given in Figure 20. This example is the data received from driver number 2.
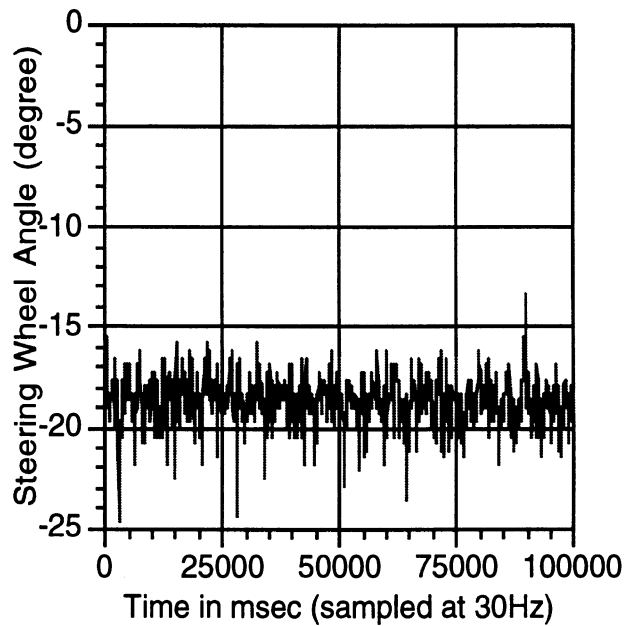

Figure 20. Sample Subject

The results of the driver calibration tests are shown in Table 4. Adding a driver in the loop increased the variation in both the speed and steering signals over the static condition. The driver caused a decrease in variation in the lane tracking signals over the static condition. This is easily understood for the speed signal. The cruise control system has more accurate moment to moment information on the speed and has predetermined algorithms to manage it. The driver has to rely on the more inaccurate

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analog display as well as driving safely. It is interesting that the lane tracker variation is smaller while steering variance has increased. This could be attributed to variation in lane width. As the markers shift back and forth the driver maintains the vehicles relative position to the markers, but this contributes to variation in the steering signal as well.

Table 4. Overview of Driver Results

	Speed		Lateral Position		Steering	
Driver	Task: Concentrate on driving at a fixed speed (no traffic). What is the mean speed indicated by the logging software and what is the speed variance?		Task: Concentrate on driving in the center of a lane (no traffic). What are the mean and standard deviation of lateral position?		Task: Keep the vehicle in a lane with a minimum of large wheel movements What is the standard deviation of steering wheel angle?	
Results (mi/hr)	55 mean mi/hr 55 st. dev. mi/hr	57.2 1.1	Right mean(ft) Right st. dev.(ft)	5.7 0.4	mean(ssu) st. dev.(ssu)	-17.5 1.5
	65 mean mi/hr 65 st. dev.mi/hr	66.0 0.9	Left mean(ft) Left st. dev.(ft)	5.9 0.4		
			Combo mean(ft) Combo st. dev.(ft)	11.6 0.2		

Evaluation Addenda

Steering Signal vs. Turn Radius

To generate data to predict turn radius for steering signal data, one experimenter drove the test vehicle around circles of nine different radii. Each circle was driven twice in each direction (for a total of 18 runs). Figures 22 and 23 show the results, separately for each turn direction and combined.
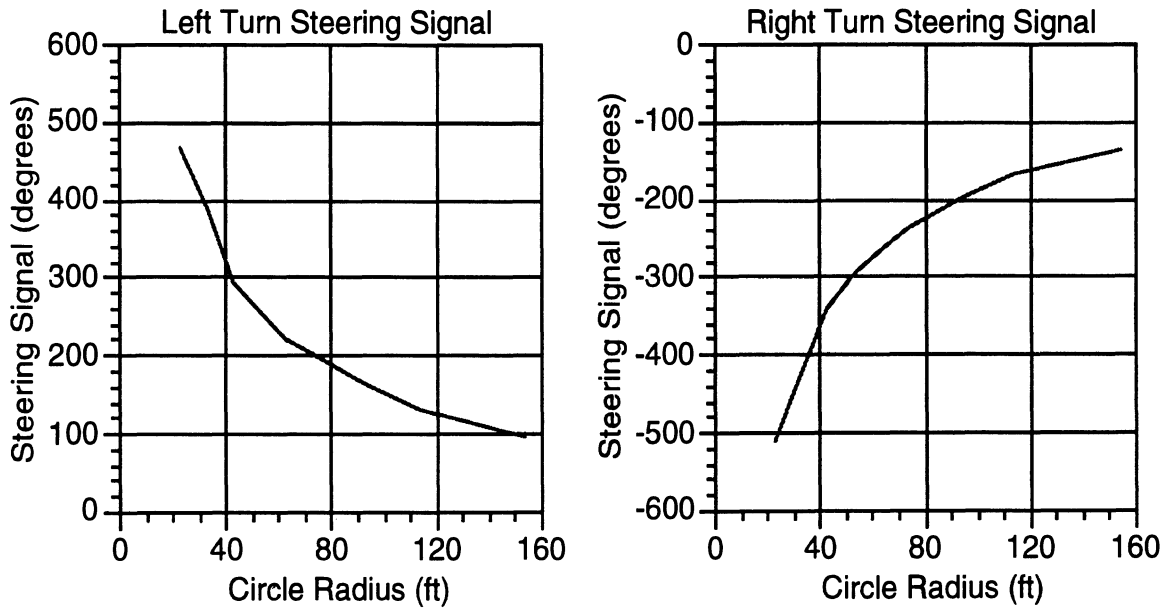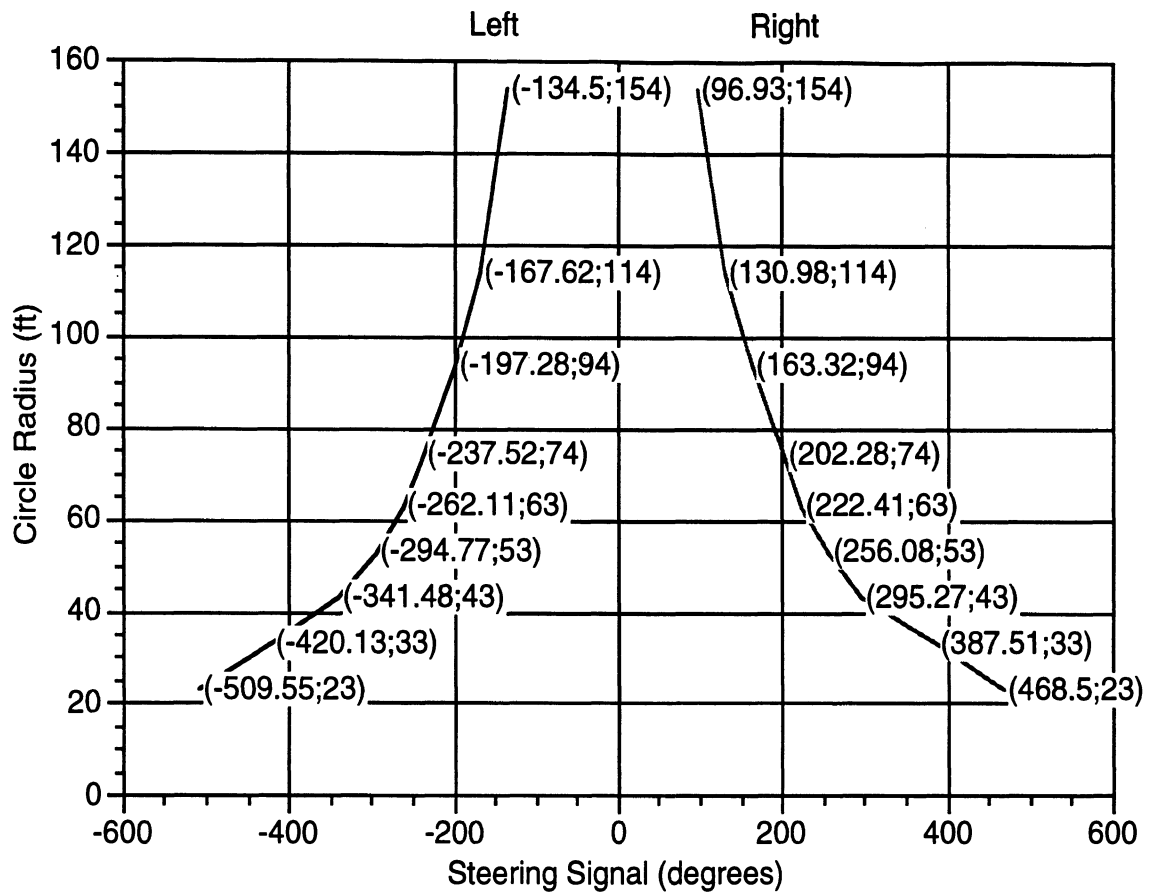

Figure 22. Steering Signal

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Figure 23. Combined Steering Signal

The following formulae, determined from regression analysis, accounts for 97 percent of the variance.

Right Turn (clockwise):

Turn Radius (ft) $= 210e^{-0.005(\text{Steering Signal(ssu)})}$

Left Turn (counter clockwise):

Turn Radius (ft) $= 251e^{0.005(\text{Steering Signal(ssu)})}$

Throttle Calibration Test

The throttle test was conducted over four subjects each performing four runs for a total of 16 trials. The throttle signal is a percentage of full throttle, thus the values range from 0 percent to 100 percent. When the instrumented vehicle was taken from zero to full throttle, it was found that the mean change from sample to sample in throttle is 0.61 percent throttle, and the standard deviation change in throttle is 0.67 percent throttle. These values give an estimate of how smoothly a driver can accelerate the vehicle. The change in throttle values were simply the differences between one value and the next. These differences represent the change in throttle for 33 millisecond segments.
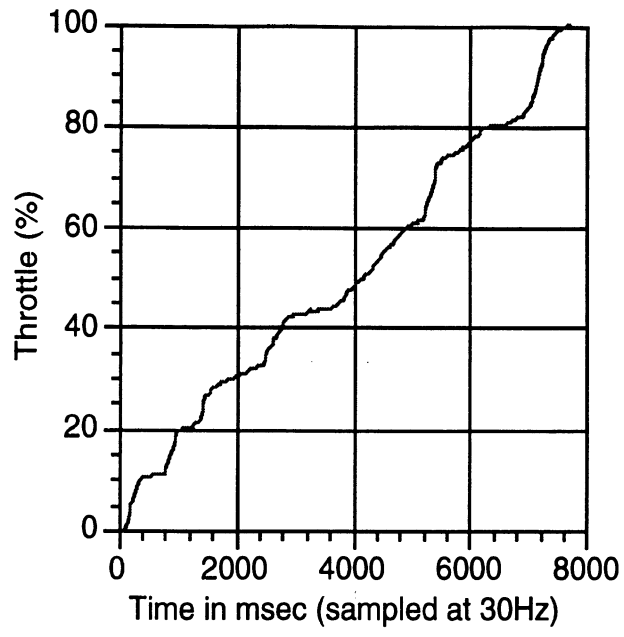
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Figure 21. Typical throttle data

CONCLUSIONS

1. How accurate are the static, dynamic, and driver-in-the-loop measurements of steering wheel angle?

   When measured statically, the standard deviation of steering wheel angle is approximately 0.8 ssu. The position offset from zero was slight and the calibration is easily corrected. For actual driving (but not correcting path errors), the standard deviation of steering wheel angle is 1.1 ssu when the steering wheel is held rigidly, 1.3 ssu when it is held loosely. When the driver attempts to minimize lane variance while driving on a straight road, the standard deviation of steering wheel angle increased to 1.5 ssu.

2. How accurate are the static, dynamic, and driver-in-the-loop measurements of lateral position?

   The standard deviation of the lateral position was 0 ft (to the nearest 0.1 ft) when measured statically. It increased to 0.5 ft when the steering wheel was held rigidly (due to vehicle drift) while driving and decreased to 0.2 ft when drivers attempted to minimize lane variance.

3. What is the relationship between the speeds reported by the computer and the speed as computed from timed runs between mile posts?

   The wheel pulse based speed estimate and timed speed estimate agreed to within 3 mi/hr, a 5 percent difference in accuracy. The standard deviation was 0.5 mi/hr.

4. When the car is under cruise control, how variable is the speed? How variable is the speed when a person drives at a steady speed?

   When the vehicle speed is controlled by the cruise control, cleaned speed signal is sinusoidal with an amplitude of 1.1 mi/hr and a frequency of 15 sec. The standard deviation of speed for flat straight roads (when the driver focuses on keeping speed constant) is 1.0 mi/hr.

5. How variable is the headway sensor data when the test vehicle is parked?

   The variance is zero.

6. What is the relationship between the computer-reported steering wheel angle and turn radius?

   Right Turn (cw):
   $$\text{Turn Radius (ft)} = 210e^{-0.005(\text{Steering Signal(ssu)})}$$

   Left Turn (ccw):
   $$\text{Turn Radius (ft)} = 251e^{0.005(\text{Steering Signal(ssu)})}$$

When the wheel is close to centered, small changes in steering wheel angle result in small tire angle changes, and consequently small radius turns. As the wheel is rotated further from the center, small steering wheel changes result in large tire angle deviation, appropriate for large turns.

On the whole the differences in system noise as compared to three states, static, dynamic, and driver in the loop, are minimal. The progression between states produced less than 2 percent increases in variation, well within the range of reasonable engineering measurements. Subsequently it can be concluded that the equipment in the UMTRI test vehicle will produce reliable and accurate data during real time driving studies.

REFERENCES

Allen, R.W., Hogue, J.R., Rosenthal, T.J., and Parseghian, Z. (1989). Data Acquisition and Analysis System Based on a Lap-Top Computer, <u>Transportation Research Record #1213</u>, 82-89.

Damkot, D.K., Geller, H.A., and Whitmore, D.G. (1977). Measuring Driver Performance: Instrumentation, Software, and Application (SAE paper 770813), Warrendale, PA: Society of Automotive Engineers.

Good, M.C., Dorey, A.D., and Joubert, P.N. (1982). Evaluation of Automobile Handling Test Procedures Using a Variable Characteristic Car (paper 82108), <u>FISITA International Congress</u>, (8-12 November 1982, Melbourne, Australia) pp. 108.1-108.7.

Green, P., Hoekstra, E., and Williams, M. (1993). <u>On-the-Road Tests of Driver Interfaces: Examination of a Navigation System and a Car Phone</u> (Technical Report UMTRI-93-35), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Green, P., Williams, M., Hoekstra, E., George, K., and Wen, C. (1993). <u>Initial on-the-Road Tests of Driver Information System Interfaces: Examination of Navigation, Traffic Information, IVSAWS, and Vehicle Monitoring</u> (Technical report UMTRI-93-32), Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Helander, M. and Hagvall, B. (1976). An Instrumented Vehicle for Studies of Driver Behavior, <u>Accident Analysis and Prevention</u>, <u>8</u>, 271-277.

Hoekstra, E., Williams, M., Green, P., and Paelke, G. (1992). <u>Usability of Text, Graphic, and Video In-car Traffic Information for Diversion Decisions</u> (Technical Report UMTRI-92-40), Ann Arbor, MI: The University of Michigan Transportation Research Institute, October.

King, D.J., Siefmund, G.P., and Montgomery, D.T. (1994). <u>Outfitting a Freightliner Tractor for Measuring Driver Fatigue and Vehicle Kinematics During Closed-Track Testing</u> (SAE paper 942326), Warrendale, PA: Society of Automotive Engineers.

Klein, R.H., Allen, R.W., and Peters, R.A. (1976). <u>Driver Performance Measurement and Analysis System (DPMAS) Volume I Description and Operations Manual</u>, (Report DOT HS 801 985), Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Kostyniuk, L. (1995). personal communication.

Leifer, J.C. (1976). Designing an Instrumented Driver Response System, <u>Public Roads</u>, September, <u>40</u>(2), 60-65.

McRuer, D.T., Peters, R.A., Ringland, R.F., Allen, R.W., Blauvelt, A.A., and Weir, D.H. (1974). Driver Performance Measurement and Analysis System (DPMAS) Task I: Requirements and Plans for Prototype Equipment (Report DOT HS 801 234), Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Mast, T.M., Ballas, J.A., and Peters, J.I. (1976). Instrumented Vehicle Research on Highway Information Systems, Public Roads, September, 40(2), 53-59.

Sewell, R. and Perratt, C.I. (1975a). A Data Acquisition System for Research Studies of Driver Performance in Real Traffic Situations (Report LTR-ST.751), Ottawa, Canada: National Aeronautical Establishment, National Research Council.

Sewell, R. and Perratt, C.I. (1975b). Data Acquisition System for Studies of Driver Performance in Real Traffic, Transportation Research Record #530, 31-45.

Sweet, R.E. and Green, P. (1993). UMTRI's Instrumented Car, UMTRI Research Review, Volume 23, January-February, 1-11.

Van der Horst, R. and Godthelp H. (1989). Measuring Road User Behavior with an Instrumented Car and an Outside-the-Vehicle Video Observation Technique, Transportation Research Record #1213, 72-81.

Verwey, W.B., Burry, S., and Bakker, P.J. (1992). ICACAD: A Tool for Human Factors Evaluation of Sophisticated In-vehicle Systems in Real Traffic (TNO report IZF 1992 C-14), Soesterberg, The Netherlands: TNO Institute for Perception.