

**Development of an Evaluation Program  
for Automotive Instrument Panel Design**

by

**Ko Kurokawa**

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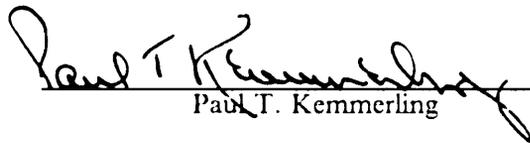
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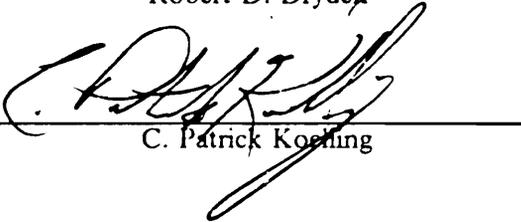
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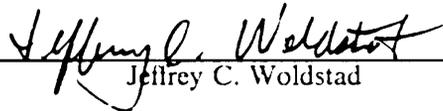
Robert D. Dryden



Paul T. Kemmerling



C. Patrick Koehling



Jeffrey C. Woldstad

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(ABSTRACT)

This dissertation research was a part of a multi-year research effort, objectives of which were (1) to characterize attentional demands of drivers performing automotive instrument panel (IP) tasks, (2) to develop a methodology to quantify the driver attentional demands, (3) to examine a variety of factors which influence the visual attentional demand (VAD) and concurrent manual demand (CMD) through a comprehensive review of previous studies and a series of experiments, and (4) to develop a computer program to evaluate contemporary and future automotive IP designs on the basis of their attentional demands.

In the first part of this dissertation, an extensive literature review of methodologies and findings concerning automotive IP task performance is presented. Most of the earlier studies reported task completion times (also referred to as response times and transaction times), which did not provide a precise detail of the operation of an instrument. More recent studies, on the other hand, recorded the driver's eye movements while performing an IP task, and measures of VAD were analyzed. Among the variety of methodologies to measure eye movements, the limbus and pupil tracking technique using a commercially available video cassette recorder (VCR) represents an ideal compromise among precision, cost, and size/weight. Combined with the traditional response time measure, the number and average length of glances, which are determined by a frame-by-frame analysis of the eye movement recording tape, allow a quantitative evaluation of driver IP task performance.

A series of three experiments conducted in the moving-base driving simulator in the Vehicle Analysis and Simulation Laboratory forms the second part of this dissertation. The objectives of these experiments were (1) to validate the use of the driving simulator for collecting driver performance data on IP tasks, (2) to examine factors which influence the simulated driving workload, e.g., introduction of random crosswind and road curvature, (3) to expand the existing database on conventional IP tasks, (4) to examine the effects of IP macro- and micro-clutter on driver task performance, and (5) to investigate the issues related to control labelling, i.e., random versus sequential labelling and label abbreviation.

Some of the important findings from the simulator experiments were (1) the driver IP task performance data collected under the zero crosswind and straight road conditions were found to be acceptably close to those in the in-car, on-road study during the first phase of this research program (Hayes, Kurokawa, and Wierwille, 1988), (2) IP macroclutter, represented by the number of instruments in the IP, was linearly related to the complexity of an IP task, reflected in the number of glances to IP, (3) IP microclutter, represented by the number of controls within an instrument, was linearly related to both complexity (number of glances to IP) and difficulty (average length of glances to IP) of an IP task, and (4) concise and distinct labels were more desirable as they required fewer glances and were located more quickly than their fully spelled counterparts.

In the third part of this dissertation, a computer program (IPanalyzer) which was developed to aid automotive IP designers in evaluation of an IP design is discussed. Users of IPanalyzer can obtain driver IP task performance estimates (1) empirically from the existing experimental data, (2) by assessing the difficulty, complexity, and manual demand of a given task, or (3) by decomposing a task of interest into elements and categorizing them by their behavioral characteristics. Instructions for using IPanalyzer are supplemented by detailed descriptions and discussions of the data on which the driver IP task performance estimates are based.

Finally, limitations of the current evaluation program are discussed, and a direction for future research and development are suggested.

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## INTRODUCTION

Today's automobiles are more capable and offer higher levels of comfort and convenience than their "horseless buggy" ancestors at the turn of this century. Drivers are surrounded by a greater number of instruments each of which is of increasing sophistication and complexity. While the technological advances that realized the state of art are unquestionably astonishing, the driving public's acceptance and utilization of the new features have not necessarily kept pace of technology. That is, the human-machine interface in the automobile has not enjoyed as much attention as the automobile itself has. Needless to say, the human-machine interface is a critical element in insuring safe and effective operation of the system.

The instruments surrounding, and thus available to, drivers may be classified in two general categories by their functions. The primary instruments are those essential to the driver's primary task, i.e., the operation of an automobile; whereas the secondary instruments are those which are not necessary but add comfort and convenience. (The distinction between these two categories is not always clear.) Obvious examples of the primary instruments are such controls as the steering wheel; accelerator, brake, and clutch pedals; gear shift lever; headlight and turn signal switches; windshield wiper switch; and displays, e.g., gauges and/or warning lights for fuel, oil pressure, battery voltmeter, and engine coolant temperature. The secondary instruments, on the other hand, provide audio entertainment, e.g., radio, cassette, and compact disc players; climate control; communication, e.g., citizen band radio, cellular telephone; navigation aids; and various other amenities.

A basic definition of automobile driving is to maintain a desired vehicle state. Through primary instruments, a driver learns of and controls the vehicle's operating conditions. The driver then interacts with the vehicle's surroundings. At the micro level of navigation, s/he maintains proper clearance around the vehicle, i.e., from other cars and obstacles, and within the driving lane. At the macro level, s/he navigates through the road system to reach the intended destination.

Almost all the information about the vehicle's present state, whether with regard to its operating conditions or its surroundings, is acquired visually by the driver. The feedback to control inputs is also received visually. Hence, there exists a visual attentional demand (VAD) for the primary task of driving an automobile. Similarly, the operation of secondary instruments involves a VAD, with a few exceptions in which the feedback involves another sensory modality, e.g., climate control and audio entertainment system.

All controls currently found in automobiles are manually operated. Some controls, such as the steering wheel, foot-operated pedals, and shift lever, are in constant contact with drivers, thus they exert only a manual demand (since automotive controls do not normally require all available limbs, the term concurrent manual demand (CMD) will be used). On the other hand, most controls are not in constant contact and must therefore be located before control inputs are made. In most cases, these controls are located visually, however brief the searching glance might be. There then exist both VAD and CMD for the driver's control inputs for these control operations.

As far as the automotive human-machine interface is concerned, therefore, the instrument design influences both VAD and CMD. At the micro level, the design features of an individual instrument, e.g, available functions, types of controls and displays, and how tasks are performed, determine the level of demands on drivers. At the macro level, how a particular instrument is integrated with the other instruments, in terms of its position and function, affects the level of demands. VAD and CMD are also influenced by driver characteristics (age, gender, experience, capability, expectancy/familiarity, and preference) and how drivers interact with the instrument design and driving conditions (vehicle and road conditions, weather, traffic, etc).

Various instrument configurations have been implemented, at both micro and macro levels, and some have been received favorably by the driving public (while others were severely criticized). There appear to be some conventions regarding the design of instruments, and the driving public has developed a certain expectancy about their functions and locations. New features have also been added, for the purpose of making the instrument more capable. Often, the result is to make

the instrument too complex and difficult to operate. There is a definite need for objective measures with which to evaluate the design of automotive instruments.

Visual attentional and concurrent manual demands are ideal constructs for automotive instrument evaluation, as they reflect the instrument's characteristics in terms of demands on drivers. Logical steps in a research program to develop this concept are thus (1) to define appropriate measures of VAD and CMD, (2) to examine precisely how these measures are influenced by such factors as age, gender, and experience, (3) to develop a model that will estimate these measures, and (4) to predict relevant driver performance based on these measures. By quantifying the driver instrument panel task performance, relative merits of alternative designs can be evaluated, and, in the future, a comprehensive method to optimize an automotive instrument panel design might be developed.

This dissertation consists of three parts:

1. An extensive literature review on methodologies and findings concerning the automotive instrument panel (IP) task performance,
2. Three driving simulator experiments to expand the existing database on driver IP task performance and to investigate additional issues that have not been studied previously,
3. An evaluation program that provides a computerized database of existing data and two procedures that provide driver performance estimates for IP tasks for which no data are available.

## PREVIOUS RESEARCH IN IP TASK PERFORMANCE

A number of studies has been conducted to measure driver instrument panel (IP) task performance. Most studies evaluated a specific type of control or compared alternative designs for a given task. The task performance at the individual instrument level, or the micro level, is undoubtedly easier to measure, and a clear understanding of the operations of individual instruments is essential before examining an IP design as a whole, i.e., a collection of instruments interacting with each other and with the operation of the vehicle (at the macro level).

These studies of the IP task performance can be categorized on the basis of their dependent variables. Many report response times, or task completion times, i.e., the times between the experimenter's instruction to subjects to perform an IP task and the completion of the task. Some studies also calculated the operation error rate, by observing the number of times in which a commanded IP task was not performed. These measures are easy to determine, either by an experimenter observing the driver's operation of instruments or through the use of an electric trigger (in case of the response time).

There are also studies which, usually in addition to response times, recorded measures of driver's eye movements while performing an IP task. While eye movement measures require extensive instrumentation, they provide a detailed look at driver's behavior while operating instruments. The visual attentional demand (VAD) of an instrument, for example, can be inferred from the measures of eye movements, and factors that influence the IP task performance can be examined in greater detail.

### Response Time Studies

The response time, or task completion time, is perhaps a higher-order measure of task performance than the driver eye movement measures. Unlike eye movement measures which provide a precise detail of the visual aspect of the driver while operating instruments, the task completion time only

reflects the “end result” of various factors which influence the IP task performance. That is, the operational detail of a task can not be deduced from the measure without knowing the condition under which the value is collected.

Most of the driver IP task performance reviewed was conducted under static, laboratory settings, and the number of instruments examined was limited. Table 1 summarizes the experimental paradigms and results of most of the static response time studies. Two other response time studies which were more comprehensive in their research efforts are discussed below. Specifically, these studies attempted to correlate the task performance with subjective factors, e.g., driver expectancy of controls.

*Malone, Krumm, Shenk, and Kao (1972)*

The study reported by Malone, Krumm, Shenk, and Kao (1972) consisted of a series of experiments and a survey. Its main contribution lies in investigating the effect of driver experience/familiarity on IP task performance and in demonstrating the merits of an IP design based on human factors principles. Throughout the experiments, response times and numbers of task errors were collected during the observations of drivers performing 20 IP control and display tasks (5 observations each).

In the first experiment, two groups of subjects drove both a 1971 Oldsmobile Delta 88, which was intended to represent an automobile with which they were unfamiliar, and their own cars on a test track. One group of 10 subjects drove during the day, while the other group of four drove at night, and no significant difference was found between these two groups. Driver IP task performance was better, i.e., shorter response times and fewer errors, in their own car than in the Oldsmobile. A follow-up experiment in which four of the subjects repeated the tasks in their own car while stationary showed that the difference between the data collected while driving on a test track and while stationary was so small that the authors recommended static testing.

Table 1. Summary of response time studies

**Kuechenmeister (1974)**

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**Instrument(s):** Multifunction stalk control

**Conditions:** Amount of practice: No prior practice  
One set of practice trials  
Practice until error-free

**Dependent Measures:** Response Time  
Error Rate

**Subjects:** 30 (15 M; 15 F) General Motors employees

**Setting:** 1972 Chevrolet station wagon  
Static  
5 functions observed

**Results:** Performance dependent on practice  
Difference in stalk switch types

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**Krumm (1974)**

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**Instruments:** Horn, footbrake, and headlight dimmer

**Conditions:** Different horn locations

**Dependent Measure:** Response Time (Simple, Choice)

**Subjects:** 336 American drivers

**Setting:** 6 different cars (4 observations each)  
Static

**Results:** Shorter RT for floor-mounted control over stalk-mounted

Horn location	Model	Simple RT (s)	Choice RT (s)
360° ring	Taurus	0.41	1.64
2-spoke lever	Olds Cutlass	0.44	1.29
Center	Fiat 124	0.62	1.65
3-spoke push button	BMW 202	1.96	1.86
Stalk	Austin Marina	9.60	2.07
Rim	Olds 98	29.00	1.61

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**Table1 (Continued)**

Middendorf, Dineen, and Habsburg (1974)

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**Instrument:** 3-beam headlight switch

**Conditions:** Column-mounted (pull-push)  
Column-mounted (delta)  
Panel-mounted (delta)

**Dependent Measure(s):** Response Time  
Questionnaire

**Subjects:** 32 drivers (16M, 16F; 16 novice, 16 experienced)  
each in Dallas, TX and Warren, MI

**Setting:** Simplified seating buck with steering wheel and display panel  
Static

<b>Results:</b>	<u>Control type</u>	<u>Dallas RT (s)</u>	<u>Warren RT (s)</u>
	Column (pull-push)	1.20	1.21
	Column Delta	1.20	1.24
	Panel Delta	1.14	1.24

---

**Instrument:** 2-beam headlight switch

**Conditions:** Column-mounted (pull-push)  
Column-mounted (ratcheted: pull-pull)  
Floor-mounted (ratcheted: push-push)

**Dependent Measure(s):** Response Time  
Questionnaire

**Subjects:** 32 drivers in Warren, MI

**Setting:** Simplified seating buck with steering wheel and display panel  
Static

<b>Results:</b>	Column (pull-push)	1.14 s
	Column (pull-pull)	1.06 s
	Floor (push-push)	1.22 s

Table 1 (continued)

**Faust-Adams and Nagel (1975)**

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**Instruments:** 6 controls  
**Conditions:** Car style (American vs. European)  
**Dependent Measure:** Response Time  
**Subjects:** 24 Australian non-drivers (16M, 8F)  
**Setting:** 1972 Holden HQ and 1971 Mazda Capella RX2  
 5 observations each  
 Static

**Results:** Mean Response Time (s) and Location

Car	Hi-Beam	Headlight	Wiper	Horn	Ignition	Handbrake
Holden	1.76* floor	1.63 dash	1.74* dash	1.46*	1.68	1.94* left
Mazda	1.36* stalk	1.67 stalk	1.44* stalk	1.34*	1.61	1.68* right

\* denotes significant ( $p < 0.01$ ) difference

Mazda headlight stalk was awkward to reach because it was shorter and located behind the turn-signal stalk.

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**Kuechenmeister (1975)**

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**Instruments:** 14 functions  
**Conditions:** Standard Oldsmobile controls (stalk- and dash-mounted)  
 vs. Chevette stalk-mounted controls  
**Dependent Measures:** Response Time  
 Error Rate  
**Subjects:** 32 drivers  
**Setting:** 1975 Oldsmobile  
 Static  
 4 observations  
**Results:** Panel-mounted controls were faster  
 Difference in performance decreased with practice

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**Table1 (Continued)**

**McCallum, Dick, and Casey (1982)**

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**Instrument:** Cruise control, headlight switch, turn signal indicator, wiper/washer switches

**Conditions:** Steering wheel-mounted switches  
Conventionally located switches

**Dependent Measure(s):** Response Time  
Error rate  
Subjective opinions

**Subjects:** 30 drivers

**Setting:** Driving for 1-1/2 hours

**Results:** Slower to use steering wheel-mounted headlight switch and turn signal indicator

More error to use steering wheel-mounted turn signal indicator

A stalk should be used for turn signal indicator

Controls, in general, should not be located on a moving surface

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In the second experiment, two groups of subjects (large car drivers and small car drivers) performed IP tasks in a stationary 1971 VW Beetle. No significant difference was found between the groups. In the following experiment, the effect of prior testing on IP task performance in subjects' own cars was tested. Two groups of five subjects each first tested in a Oldsmobile or a VW, and then tested in their own cars; another group of ten repeated tests in their own cars. While there was no significant difference in the task performance in own cars, a significant difference was again found between the unfamiliar car, i.e., the Oldsmobile and VW, and own cars. Familiarity with an IP design was thus found to have a significant effect on task performance.

In yet another experiment, a group of ten subjects from the previous experiments performed the IP tasks using two mock-up IPs designed with human factors considerations. The result showed a small difference between IPs from subjects' own cars and the human factored IPs, which indicated that drivers performed as well as with these unfamiliar, yet human factored, IPs as with the familiar IP. As the IP task performance seems largely dependent on the drivers' experience/familiarity with the IP, it is interesting to see how well drivers will do using a human factored IP after some practice (to examine relative strengths of familiarity and human factors principles on task performance).

In the last experiment, four configurations for a three-beam headlight switch were compared using 6 subjects. These configurations were (1) a button on the steering wheel spoke, (2) a rocker switch on IP, (3) a stalk moving along the steering axial, and (4) a stalk moving in a triangle pattern ("delta"). The response time was longest for the IP rocker, followed by the delta stalk. The spoke button and the regular stalk were quickest, and there was no significant difference between these two configurations.

The survey of IP controls and displays (also Kao, Malone, and Krumm, 1972) was intended to determine the degree of location, operation, and coding standardizations among 1972 (year) automobiles. It investigated the locations of 19 controls and 14 displays in 37 car groups and found that the average location commonality was 53.25 % among the 1972 cars. The authors also tested to determine (1) whether IPs of similar-sized cars resembled one another more closely and (2) whether

IPs of same manufactures resembled one another more closely. Lastly, the controls and displays were evaluated for their “operability”, i.e., in terms of errors and times to operate. It was concluded that there were more operability problems in controls than in displays among the 1972 cars.

### *Anacapa Sciences (1976)*

This study conducted by Anacapa Sciences (1976) is one of the most comprehensive research efforts to date on the issues related to automotive control locations. Its objectives were (1) “to determine the controls for which performance data were needed to establish (location) standardization requirements”, (2) to determine the degree of control location standardization required, and (3) “to determine whether or not there were preferred locations and designs for the standardized (control) items.” This research effort consisted of:

#### 1. Problem definition and analysis

- Problem incidence survey (own-car): 1140 drivers
- Problem incidence survey (rental car): 342 drivers
- Vehicle commonality survey

#### 2. Methodology development and validation

- Develop a questionnaire on control location expectancy
- Own-car control location recall test: 28 U.S. drivers
- Slide performance test: 24 U.S. drivers; 30 cars
- On-road performance test: 12 U.S. drivers; 2 cars + own car

#### 3. Driver expectancy survey (questionnaire)

- 1708 U.S. drivers
- 238 European and Japanese drivers

#### 4. Control locating performance test: 2088 U.S. drivers; 2 cars

In the Phase 2 slide performance test, subjects were shown rear-projected color transparencies of 30 different IPs (twenty-four 1973 cars, domestic and import, and six older cars) in the laboratory and asked to locate and touch one of eight controls. Response times and error rates were measured from two observations of each control in the thirty IP configurations. The results of this experiment showed that the easiest control to locate was the radio, followed by the ignition switch, climate control unit, headlight switch, wiper switch, cigarette lighter, hazard switch, and vent control. The controls which the subjects had more difficulty locating were the same ones which drivers reported as difficult to find in the Phase I surveys.

The authors of this study also presented the response time data in an innovative way, called the cumulative response time (Figure 1). Basically, this figure shows a frequency distribution of response times integrated over the frequency, and a point on the curve indicates the probability of drivers locating a specific control in a response time shown or less. As can be seen in this figure, the degrees of difficulty with which to locate these controls remain constant among the IP configurations.

The authors also report a high ( $r = 0.85$ ) correlation between response times and error rates and a correlation of  $r = 0.54$  between the drivers' control location expectancy and both response times and error rates.

In the Phase 2 on-road test, 12 U.S. drivers located 10 controls (5 times each) while driving in three different cars. A 1974 Ford Torino represented a car with a low expectancy IP, while a 1974 Pontiac Catalina was considered a high expectancy car. The third was each drivers' own car. Although both the response times and error rates were greater in the previous static experiment, the authors of this study concluded a "reasonably good agreement" between these two Phase 2 experiments. They also noted that response times were shorter for IP-mounted controls than stalk-mounted ones.

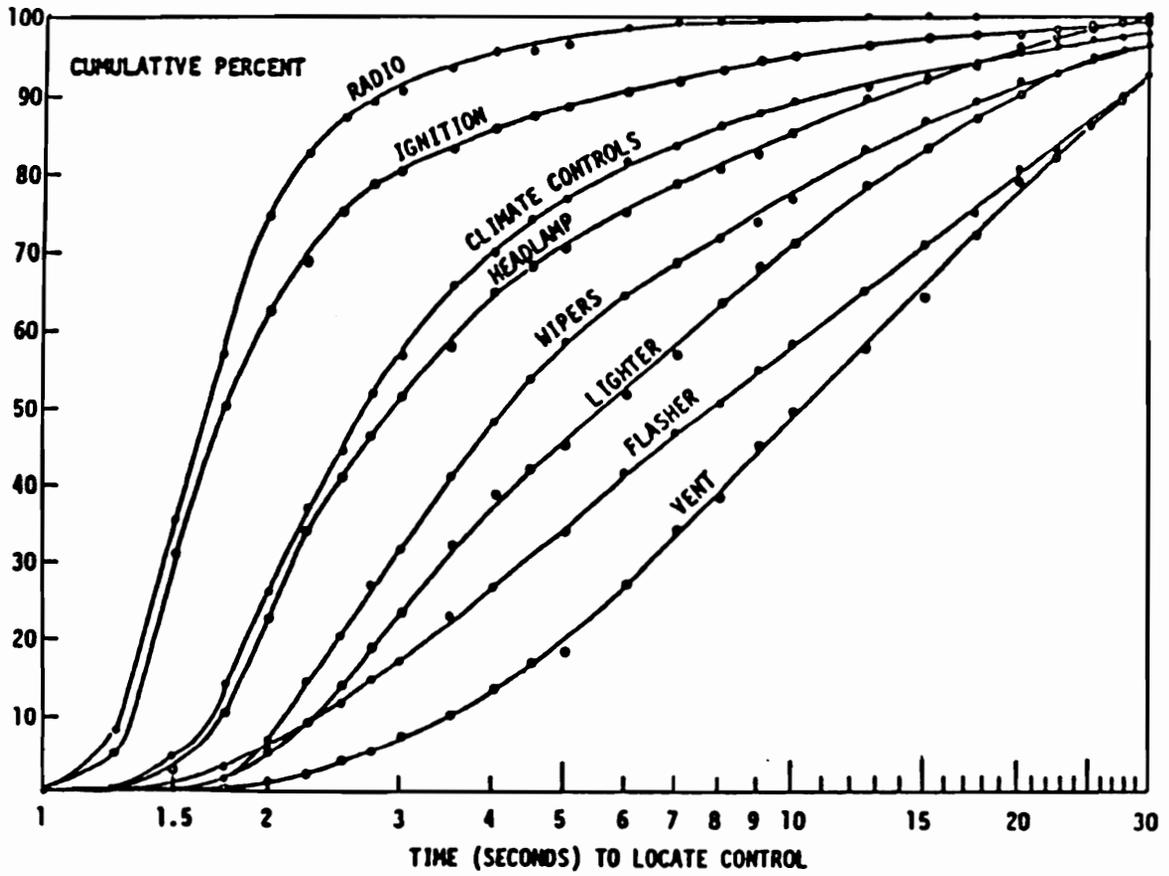


Figure 1. Cumulative response times for controls (Anacapa Sciences, 1976)

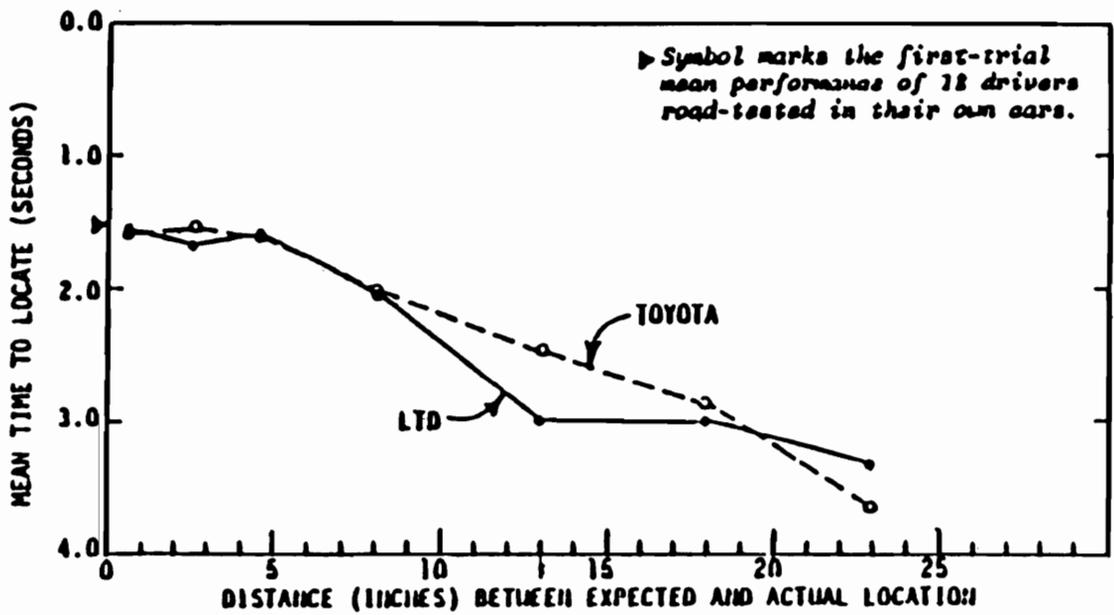
Lastly, during the Phase 4, response time data for eight controls were collected from 2088 U.S. drivers under a static condition. The IPs were removed from a domestic station wagon (1973 Ford LTD) and an import subcompact (1969 Toyota), and each subject was shown one of the 30 and 15, respectively, different IP configurations that were created for each car. Following the trials in both cars, subjects provided information about their control expectancy, i.e., with regard to the location and its strength. The authors reported that the response times were linearly related to the distance between the actual and expected locations of the control (Figures 2 through 4) and suggested a “seven-inch rule.” That is, so long as a control is within seven inches of the expected location, the task performance will not suffer from the discrepancy. They also stated that most performance degradation was due to a driver’s uncertainty over the location of a control.

Based on the surveys and performance tests, the authors of this study made the following recommendations on control locations:

- Headlight and wiper/washer switches should be located on the IP’s left side
- Radio and climate control on the IP’s right side
- Cigarette lighter and ashtray within the lower part of the right side, the edge of IP, or the upper part of the console. The lighter should not be located within the ashtray
- Standardize the location of the hazard flasher to the steering column or IP
- Vent control should be integrated with the climate control

### Eye Movement Studies

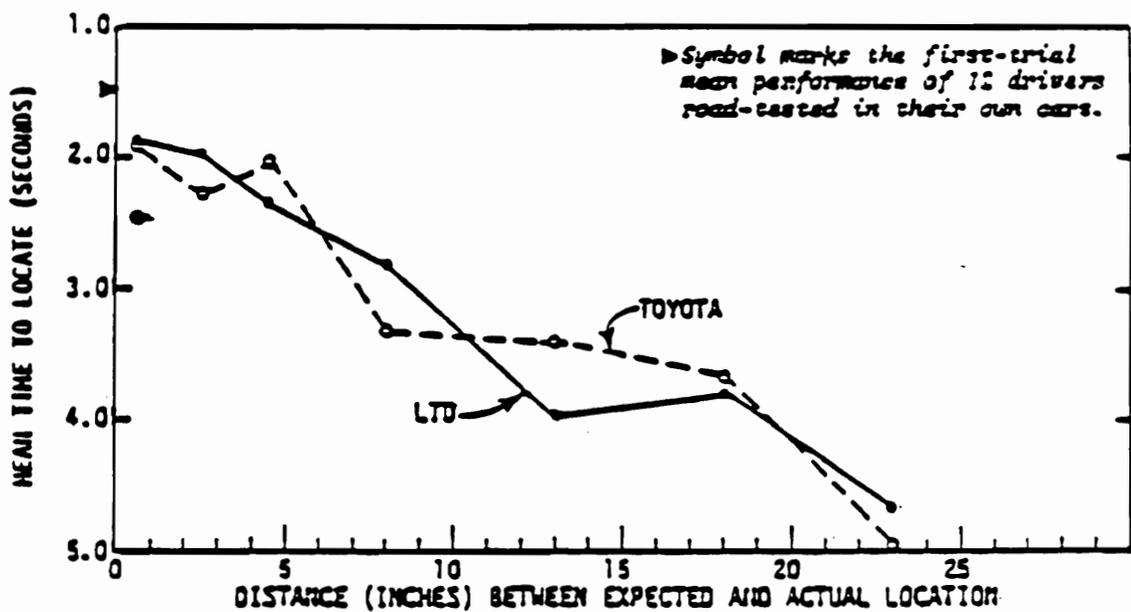
Because the role of vision is essential in the operation of an automobile and its instruments, much can be learned from monitoring the driver’s eye movements. By examining the duration and frequency of eye glances to a certain task, be it driving or an IP task, the visual attentional demand (VAD) characteristics of the task can be evaluated. Comparisons of these glance variables for different tasks can then be used to estimate their relative importance and the driver’s attention sharing



LTD $\bar{M}$	= 20	70	37	42	10	43	33
TOYOTA $\bar{M}$	= 35	61	34	22	30	50	31

Mean Time to Locate the Headlight Switch as a Function of the Distance between the Expected and Actual Locations.

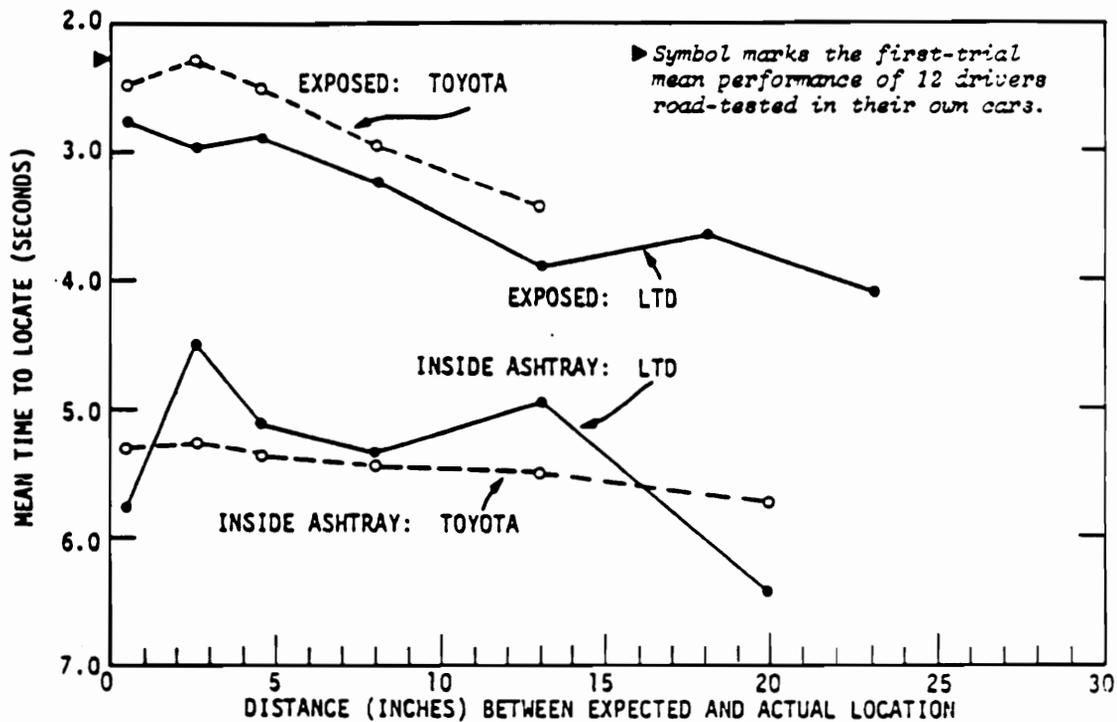
Figure 2. Control location discrepancy for headlight switch: Anacapa Sciences, 1976



LTD N =	29	58	43	40	15	43	33
TOYOTA N =	35	47	37	32	40	53	24

Mean Time to Locate the Wiper/Washer Switch as a Function of the Distance between the Expected and Actual Locations.

Figure 3. Control location discrepancy for wiper/washer switch: Anacapa Sciences, 1976



LTD N = 12	30	40	93	27	8	6	(EXPOSED)
TOYOTA N = 17	26	28	69	32			
LTD N = 2	5	7	18	7		5	(INSIDE ASHTRAY)
TOYOTA N = 6	17	14	26	22		3	

Mean time to locate the cigarette lighter as a function of the distance between the expected and actual locations.

Figure 4. Control location discrepancy for cigarette lighter: Anacapa Sciences, 1976

strategy. Similarly, the eye transitions among tasks would indicate their association or the sequence of their operations.

Eye movement variables are lower-ordered and thus more direct measures of driver task performance that can provide more information about a task than can a response time alone. The means to quantify eye movements are, however, more complex and difficult than response times, which only require a stopwatch. Briefly described below are the more common techniques to measure eye movements (a fairly comprehensive review is provided by Young and Sheena, 1975).

#### *Methods of eye movement measurements*

**Contact lens method** This technique offers the most precise (resolution of 5 - 10 arc seconds) means to measure eye movements. Because conventional contact lenses are too mobile, all measurement systems use special lenses which fit more tightly. The most common system utilizes a mirror that is attached to the lens and reflects light to outside detectors. Other systems include a lens with a multiple line pattern and a lens with small coils which induce voltages from the magnetic source outside. Disadvantages of the contact lens method are its small range (less than 5 degrees), discomfort and possible injury for subjects, and its high cost.

**Corneal reflection methods** This method utilizes a virtual image in the corneal bulge, which, due to the geometry of the eye, moves in the direction of eye movement, relative to the head. There are two methods which utilize this interesting characteristic: head-mounted corneal reflex techniques and corneal reflex point of regard measurements.

The basic principle behind the corneal reflex point of regard method is to determine the eye position from an outside image reflected off the cornea. For example, if a person is looking directly at a point light source, its reflection will appear at the center of his/her pupil. If s/he is looking off the point, the space on which s/he is fixating can be determined either by measuring the difference between the center of his/her pupil and the image of the light source or by noting which of multiple

light sources is seen in the center of his/her pupil. Commercially available examples of this method include the Honeywell Oculometer and the Whittaker eye movement monitor. The advantages of this method are (1) that it is not intrusive and (2) it has a broad range (40 degrees and up); the disadvantages are that it is (1) bulkier, (2) expensive, and (3) not as accurate (resolution of 1 - 2.5 degrees) as some of the other methods described in this section.

The head-mounted corneal reflex method uses a light source that is attached to the subject's head, and eye position is determined relative either to the head position or to the subject's field of view. An example of the latter is a head-mounted corneal reflex camera which records the field of view through a miniature camera or fiber optics cable from the lens worn by the subject. In these systems, the corneal reflex, measured as a reflected spot of light from a peripheral lamp, is optically combined with the field of view, and the eye position can be precisely determined from the picture. The camera system offers a range of 12 - 15 degrees and a resolution of 2 degrees (0.5 degrees in a head-fixed camera).

The corneal reflex camera systems were used by Mourant and Rockwell (1970) and Cohen (1981) in their investigations of eye movement patterns in driving. In Mourant and Rockwell (1970), search and scan patterns of drivers travelling on expressway were mapped. The authors found that (1) during the open-road driving, the patterns became more compact over trials and shifted down and to the left and (2) the car following task was characterized by more frequent checking of the car position within the lane, a decrease in checking road signs, and a lower line of sight, i.e., looking closer ahead.

In Cohen (1981), where drivers looked in order to maneuver around an obstacle in the roadway was examined. The author reported that drivers directed their attention to their path around the obstacle, rather than the obstacle itself. When another group of drivers were presented a slide of the same traffic situation, they were found to focus their attention to the obstacle and also to have a longer glance at objects.

**Double Purkinje image eye tracker** In addition to the corneal reflection (the first Purkinje image), which occurs at the surface of cornea, there are several more reflections as light goes through the eye. These reflections move differentially under eye rotation, and the difference in image between the first Purkinje image and the fourth Purkinje image which occurs at the rear surface of lens can be used to determine eye movements. These two images are optically directed to separate photodetectors, and servomotors move the optics to superimpose these images. The resultant electrical signals are then used to determine the eye position. This eye tracker system offers a range of  $\pm 15$  degrees with a 2 minute of arc resolution and a high response frequency. The drawbacks are that (1) it requires high illumination to detect the fourth image, (2) it is a very complex (and thus expensive and bulky) system, and (3) in order to achieve such an accuracy and sampling rate, a subject's head must be stabilized.

**Electro-oculography (EOG)** This method measures eye movements through the corneoretinal potential, which exists between the cornea and retina as the result of the latter's higher metabolic rate. The electrostatic dipole rotates with the eye, and eye movements can be monitored by measuring the potential difference with skin electrodes placed around the eye. This method can provide the largest range (up to  $\pm 70$  degrees, horizontal) at a resolution of  $\pm 1.5 - 2$  degrees. The potential disadvantages are (1) its susceptibility to extraneous noises and thus artifacts and (2) nonlinearity (particularly above  $\pm 30$  degrees). Several eye movement studies which utilized this method are discussed later.

**Limbus and pupil tracking** This is perhaps the most intuitive and easiest means to measure eye movements relative to the head. Depending on the level of precision with which the eye position is measured, the limbus and pupil tracking can provide a useful range ( $\pm 15$  degrees, horizontal) at a resolution of 15 - 30 arc minutes; the vertical eye position is, however, more difficult to measure. At the current state of automotive IP research, where the eye position needs not be determined with such a precision, this method is easiest and thus least costly to implement than any other methods. The use of a commercially available video (or motion picture) camera can provide the

information about driver eye movements that are pertinent in evaluating instruments. Many of the eye movement studies discussed later therefore utilized this method.

In selection of an eye movement measurement technique, the following issues must be considered and an appropriate trade-off made:

- Cost
- Accuracy and precision
- Intrusiveness
- Subject comfort and safety
- Adaptability to the testing environment

Size, weight, and power requirements

Instrumentation complexity

Required illumination

Susceptibility to vibration and other ambient factors

*Mourant, Moussa-Hamouda, and Howard (1977)*

The objectives of Mourant, Moussa-Hamouda, and Howard (1977), which included the first eye movement study of automotive IP task performance, were (1) to survey the frequency of problems associated with locating and operating “fingertip reach”, specifically stalk, controls, (2) to conduct laboratory tests which determined appropriate performance measures and compared certain types of stalk controls, and (3) to make recommendations concerning fingertip reach controls. Four hundred and five drivers of 31 cars were interviewed about their experiences with fingertip reach and stalk controls. The survey was followed by an experiment which compared five stalk configurations

and three panel-mounted controls (also Mourant, Herman, and Moussa-Hamouda, 1980). Each of the five groups of 16 subjects (8 male and 8 female, 20 - 50 years of age) performed IP tasks (4 observations each of 25 tasks) using one of the five configurations (Figure 5) while performing a tracking task in a buck. Their performance was measured in (1) the number and duration of “direct looks” which were defined to be the time when driver’s eyes were off the forward scene, (2) the hand movement time, between when the driver’s hand left the steering wheel and touched a control, and the “operation” time which is the time between when the subject’s hand touched a control and the control was activated, and (3) tracking task performance. All of these measures were collected with three television cameras (the eye movements were presumably determined by the limbus and pupil tracking). The results indicated that (1) the frequency of direct looks increased as the reach distance increased, (2) the duration of direct looks were slightly longer to stalk controls than to the panel-mounted ones, attributable to hand orientation and eye accommodation, and (3) significant differences were found in performance times among the five stalk configurations.

The task performance times which were measured in this study were unique in that the authors measured the hand movement time and the time, after locating a control, to manipulate and activate the control. These measures provided a more detailed picture of concurrent manual demand (CMD) than other studies that have been reported (unfortunately, the reaction time, between when a driver decided to perform a task and until a hand movement was initiated, was not recorded). Also, how the glances made to the tracking task were affected by the different configurations and tasks, i.e., the competing visual attentional demands (VADs), was not reported. However, this study demonstrated the feasibility of the limbus and pupil tracking method using a videocamera in automotive IP task performance research.

In conclusion, this study provided a list of the more common types of operational errors associated with stalk controls (survey results), findings and recommendations about specific types of stalk-mounted controls (experiment results), and overall recommendations on “fingertip reach control” configurations.

Group	Multifunction stalks	Wiper (2 speeds) and Washer Function
I	Rotate back 	Wiper: rotates toward instrument panel Washer: button on end of stalk
II	Button 	Wiper on/off: button on end of stalk Wiper speed: rocker switch Washer: hand switch moves toward steering column
III	Hand switch 	Wiper on/off: hand switch moves toward steering column Wiper speed: rocker switch Washer: button on end of stalk
IV	Rotate forward 	Wiper: rotates toward driver Washer: button on end of stalk
V	Slide switch 	Wiper: slide switch pushes toward steering column Washer: button on end of stalk

Figure 5. Multifunction stalk configurations: Mourant, Herman, Moussa-Hamouda, 1980

*Heintz, Haller, and Bouis (1982)*

Heintz, Haller, and Bouis (1982) is the first study which reported the use of electro-oculography to measure driver eye movement during automotive IP tasks (also Haller, Bouis, and Heintz, 1981). The authors compared two distinct keyboard designs in a 3- and 4- digit numeral entry task (three different placements of a keyboard and the accompanying display were also examined). One configuration was a conventional telephone keypad, while the other was called a "sequence" keyboard, of which operation consisted of a key for each digit and the repeated pressing of a key to reach the desired number (sequential selection) for each digit (e.g., press thrice to enter 3). The authors postulated that such a sequence keyboard would allow a "blind operation" of a trip computer while driving. The study (involving 4 subjects) consisted of an experiment in a driving simulator and another in a test car (no further detail was provided about the experiment) and measured (1) the duration and time sequence of key actuation which provided the "total data entry time", (2) the number of changes in the (vertical) line of sight during a key entry and the duration of glances to IP, and (3) tracking task error (in the simulator) and "pedal reactions" (in the test car).

Based on their results, the authors found that (1) drivers took twice as long to enter a 3-digit number using the sequence keyboard as the conventional keyboard and (2) more control errors and longer fixation times were recorded on the telephone keypad than the sequence keyboard. They used the latter finding to conclude that the conventional telephone keypad exerted a greater visual demand on drivers and supported their argument by stating the subjective preference expressed by the subjects for the sequence keyboard. While the demonstration of electro-oculography for automotive IP task performance research was useful, because the details of these experiments were reported sparingly, the results did not go far beyond the demonstration of an alternative eye movement measurement method.

*Rockwell (1983)*

The author who successfully implemented the corneal reflex camera method for measuring driver eye movements (Mourant and Rockwell, 1970; Rockwell, 1972) switched to the limbus and pupil tracking method in this study. While the corneal reflex camera can provide a large amount of information about the driver's eye movements, its implementation in the automotive research is difficult, particularly in the in-car, on-road environment. Hence, as long as the simpler limbus and pupil tracking method utilizing a videocamera provides the level of information necessary for the objectives, its use is preferable to the corneal reflex method. Indeed, six of the eight studies discussed in this section (the other two using electro-oculography) utilized the simple limbus and pupil tracking method using a videocamera.

The objectives of this study were two-fold: (1) to assess, in a high driving workload situation, the amount of time drivers were willing to visually leave the road scene to perform conventional IP tasks (namely, AM/FM and CB radio, mirrors, and speedometer) and (2) to estimate, in a simulated driving condition, the visual time required to locate and activate controls in a "reconfigurable touch control display (RTCD)", or a touch panel display.

In the first experiment, 31 subjects (18 male and 13 female; age 18 - 71) drove a 1982 Buick Regal stationwagon through a preselected route (predominantly expressway with moderate to heavy traffic) and performed seven types of conventional IP tasks upon a verbal command from an experimenter. Driver's eye movements were monitored (at a resolution of 0.06 seconds) by a rear-seat-mounted videocamera (with a dashboard-mounted mirror), and a glance was defined to be the time during which the driver's eyes were off the forward roadway scene. The results showed (1) the average number of glances to IP of 4.6 per task (see Table 2 for the task means) and the average length of glances of 1.26 seconds, which indicates the average total glance time to IP of 5.8 seconds, (2) that the number of glances per task decreased with learning, (3) that no significant difference in the average length of glances to IP was found between the age 23 - 40 and 40 + groups,

while a shorter glance was made by the under 23 group, and (4) that the female group also made a significantly shorter glance (1.21 seconds) than their male counterpart (1.31 seconds).

Based on the results of this experiment, the author concluded that (1) a fairly consistent strategy existed for time-sharing between driving and IP tasks, (2) the average length of glances to IP was relatively independent of the tasks and more dependent on the driving task, and (3) for a more complex task, more glances, rather than longer glances, were made.

In the second experiment, the effects of size, separation, location, and shape coding of targets in the touch panel were investigated in a 1981 Pontiac Bonneville buck. Forty subjects (24 male and 16 female; age 18 - 55; 6 from the previous experiment) participated in a 45 minute session. Their eye movements were monitored by a videocamera (at a resolution of 0.06 seconds), and head movements were also measured with a head-mounted lamp and wall-mounted photoelectric sensors. Hand-off-wheel times, which are the time during which driver's hand is off the steering wheel, touch panel activation errors, simulated driving ("concurrent car following" task) performance were also measured.

The author found (1) no significant difference between genders in the average and total length of glances to IP and hand-off-wheel time, while the male group made more glances per task to IP than the female, (2) that target discrimination, i.e., time to locate a target, required 80% of the time to complete a task, (3) that shape coding helped guiding a hand to a target rather than locating it. Furthermore, (4) target separation was found to be more critical than size. The author postulated that the "visual segmentation" determined the target search process and the configurations which made it easier, i.e., small targets with large separation, resulted in a better performance (a large separation also made it easier to touch the target). For touch panel configurations containing 6 to 9 targets, large targets with minimum separation were reportedly as effective as small targets with a large separation.

Table 2. Summary of glance duration data (Rockwell, 1983)

Percent of Data	Type	Mean	Mode	Range	10%	95%	S.D.	Max	Med	Min
68.34	R/CB	1.27	1.08	3.30	0.72	2.15	0.43	3.40	1.20	0.19
11.65	RD	1.32	0.90	2.64	0.70	2.16	0.46	2.94	1.25	0.30
2.67	RG	1.12	0.66	1.68	0.66	1.90	0.44	2.22	1.08	0.54
7.93	LD	1.20	1.00	2.76	0.04	2.16	0.44	3.06	1.14	0.30
3.61	LG	1.06	0.96	1.98	0.66	2.00	0.42	2.52	0.96	0.54
5.77	HT	1.20	1.44	4.20	0.72	1.98	0.56	4.44	1.20	0.24
100.00		1.26	1.08	4.26	0.72	2.16	0.48	4.44	1.20	0.18

\*key: R/CD = Radio/CP  
 RD = Mirror, right discrimination  
 RG = Mirror, right detection  
 LD = Mirror, left discrimination  
 LG = Mirror, left detection  
 HT = Headturn

With regard to target density, (5) an increase resulted in corresponding increases in both the number and average length of glances to IP. The author stated that a touch panel should not contain more than 20 targets.

While the average length of glances to IP was independent of tasks in the in-car experiment, it was found to be dependent on touch panel configurations in this experiment. The author felt that the length of a glance to IP was related to the degree of uncertainty which a driver was willing to allow while driving on the road (by taking eyes off the road). In this laboratory experiment, higher variances in the dependent measures were found, which the author attributed to the "novelty of the (touch panel) displays" and "lack of risk" in a simulated driving. It may be that as the "uncertainty" in the simulated driving task was less (i.e., more predictable) and the consequence of an error was insignificant, the subjects maintained the "roadway" glances to be more constant and allowed the IP glance to vary according to the difficulty of locating a target.

Finally, the author suggested a procedure and a coefficient to adjust the laboratory values to the in-car, on-road estimates and stated the need to validate the laboratory findings.

#### *Monty (1984)*

An in-car, on-road evaluation of touch panel displays was conducted at Virginia Polytechnic Institute and State University in 1984. This study involved three cars with different IP configurations: (1) a 1981 Buick Riviera with a conventional IP, (2) a 1983 Riviera with a 1984½ touch panel display prototype, and (3) a 1984 Buick Electra with a 1986 touch panel display prototype (the two prototypes differing in their locations in dashboard, the number of available functions, and the display format). Fifty-two subjects (26 of each gender; groups of age 18 - 30 and 45 - 70) performed a variety of IP tasks which were categorized into: (1) radio, (2) trip monitor, and (3) climate control (HVAC) types, while driving one of the three vehicles through four types of preselected routes: (1) interstate, (2) 4-lane U.S. highway, (3) a 2-lane state road, and (4) city/town streets (four observations of each combination of these two independent variables per subject).

The dependent measures in this study were:

1. Task completion time, i.e., the time between the experimenter's verbal command to perform a task and when the subject completes the task
2. % successful task completion
3. Driver speed control (in 3 levels: +/- 2 mph or less, +/- 2 - 5 mph, +/- 5 mph or greater)
4. Lateral lane control (in 3 levels: in, at edge, or out)
5. Frequency of braking
6. Duration of braking
7. Frequency of eye glances (to three directions: road, IP, and other)
8. Variance in the frequency of glances
9. Average length of glances (to each of the three directions)
10. Variance in the average length of glances

The number of successful task completion and lateral lane control measures were noted real-time during the experimental session, while drivers' eye movements were recorded by a rear-seat-mounted videocamera (and a dashboard-mounted mirror) and analyzed, after the session, to determine the values (no estimate on the precision of the measurements was given).

In summary, the results of this study indicated that the driving and IP task performance were poorer in the touch panel display equipped cars than in the conventional IP equipped car. The task completion time was shortest and the % task completion best with the conventional IP, followed by the 1986 prototype, and worst with the 1984½ prototype (significant differences among all three in task completion time). The 1986 touch panel display's location, closer to the driver, was perhaps the reason for this ordering. The 1986 prototype equipped car also did better than the 1984½ prototype equipped car in speed and lane control measures, due to the car's improved handling characteristics. In brake frequency and duration, glance frequency and duration, and variance in glance frequency, the conventional IP equipped car fared best, i.e., least frequency, shortest duration, and least variance, while the touch panel display equipped cars did poorly. The author stated

that the drivers compensated for the increased attentional demand of the touch panel display by increasing the number of glances to it, rather than increasing the length of glances.

This result agrees with the intuitive notion that the use of a touch panel display is more complex than conventional IP tasks. Since it replaces a collection of dedicated instruments with one multi-functional control/display, drivers can no longer locate and operate a desired instrument by its physical feature, i.e., location, distinct look and feel, but select the desired function through a maze of “softkeys” on a touch panel. While the difficulty of each step, or a task element, of making a selection might not be greater, a whole task is likely more complex, i.e., requiring more steps, with a touch panel display. Clearly, the designs of particular touch panel displays used in this study were deficient and had a detrimental effect on driving and IP task performance. In order to exploit fully the many advantages of a touch panel display, improvements were needed.

Comparisons among types of tasks showed that the performance during radio related tasks was consistently poorer. While these tasks were only slightly more difficult to perform than the other task types, i.e., trip monitor and HVAC, with the conventional IP, the subjects did much worse with the touch panel displays. Among the radio related tasks (manual tuning of a radio, use of the seek feature, adjusting the speaker balance, and setting a preselect station key), the tuning task took longest, followed by the balance adjustment. The author offered several possible reasons for this observation. These tasks required a “continuous” control of the instrument, i.e., the task required a feedback, be it visual or auditory, to make the necessary adjustment. Both touch panel display prototypes (1) had a fixed “slew rate” which did not allow drivers to increase the rate of change (and thus to achieve the rate possible with the conventional instrument’s continuous knob control), (2) lacked a tactile feedback which allowed drivers to press a non-active or wrong area, and (3) may have required more visual sampling of the display, as reflected in the greater number of glances, due to the lack of proprioceptive feedback. In addition to the degraded task performance, the author felt that the drivers set a higher priority on the IP tasks in attention allocation and compromised the primary task of driving, which resulted in the poorer lane performance and the more frequent and longer application of brakes during these radio related tasks.

Among the other factors investigated, the road type influenced only the driving performance and not the IP task performance. The driving performance was found to be poorest in the 2-lane state road. With regard to the driver age, the younger (18 - 30) performed better in both driving and IP tasks. Older subjects evidently made a greater number of glances to IP, and the variance was wider (this latter finding was in contrast to the results of several other studies). The author attributed the older drivers' poorer performance to (1) presbyopia and consequent difficulty in reading the labels on a touch panel and (2) their resistance to newer technology, reflected in their difficulty in learning to use the touch panel display. Finally, gender was, in general, not an important factor; the female drivers, however, made more glances than the male.

*Heintz, Bouis, and Haller (1985)*

Another study using electro-oculography was reported by the authors of a study discussed earlier. They investigated the depth and width characteristics of a hierarchical menu system for use in the automotive IP computer system. Using a system consisted of 7 keys and a display, 6 subjects performed tasks similar to those of conventional IPs in a driving simulator. In addition to the electro-oculogram, the steering behaviors and task error rates were measured, and subjective ratings (in a questionnaire) were also collected after the experiment. The results showed (1) the number of parallel selections was not a critical factor in the average length of glances to IP, (2) an advantage for the integrated menu system over a conventional IP (i.e., a collection of independent instruments) based on the total glance time to IP, and (3) a 2-level menu was better accepted among the subjects. Once again, although the issue investigated was of interest, enough detail was either not reported or not considered in the design of the experiment(s), and thus the findings were of limited value.

*Dingus (1987)*

In this in-car, on-road study, an electronic moving-map navigation aid was evaluated, and the task and driving performance and visual attentional demand (VAD) during its operation were compared

with those of conventional IP tasks. Eight navigator tasks and 19 conventional IP tasks were divided into four categories based on prior estimates of their VADs. Thirty-two subjects, who were categorized (into cells of 4 each) by their gender, age (under 25, 25 - 35, 36 - 49, and 50 + ), and driving experience (2,000 - 10,000 miles driven annually and 10,000 + miles), drove an instrumented 1985 Cadillac Sedan deVille through three types of preselected routes (4-lane limited access highway, 2-lane state road, and residential streets).

The most extensive battery of dependent variables were measured during this study:

1. Task completion time
2. Number of task errors
3. Number of glances (to three directions: road, IP, and other)
4. Average length of glances (to each direction)
5. Total glance time (to each direction)
6. Lane maintenance (in or out of lane)
7. Average duration of lane excursion
8. Steering wheel velocity
9. Accelerator pedal position and velocity
10. Number of brake applications
11. Average duration of brake applications

During each experimental session, the driver task performance variables (1 - 7) were measured real-time by the experimenters (driver's eye movements were monitored through a hood-mounted videocamera), and the driving performance variables (8 - 11) were recorded real-time by the on-board IBM PC microcomputer. An experimenter also recorded the level of traffic density (light and moderate) during the sessions.

The eight navigator tasks and 19 conventional IP tasks were ranked by task completion time (Table 3), total glance to IP (Table 4), number and average length of glances to IP (Table 5), and average

length of glances to the roadway (Table 6). Functional grouping of these tasks, i.e., to group tasks with similar values, was also made using t-test and Bonferroni multiple comparisons and cluster analysis (Table 7).

Seven of the eight navigator tasks resulted in the seven longest average lengths of glances to IP. The author attributed these longer glances to the complexity of information presented by the navigator display and thus the increased difficulty in extracting necessary information in each step. However, the author noted that considering the size of variance due to other driver and road related factors, the difference in length of glances between the navigator and conventional IP tasks were not large enough to conclude that the information presented by the navigator was too complex for the driving environment. In fact, in terms of the number of lane excursions, the driving performance was worst during two conventional IP tasks: manual insertion of a cassette tape and power mirror adjustments. Nevertheless, the amount of information presented at each step of a navigation task should be controlled to provide an optimum balance between the length of glance required to extract the information and driver's information needs (to complete the task). This issue is applicable not only to navigation aids but also to any multifunctional instruments, e.g., touch panel displays. For this navigation aid, the author suggested an auto-zoom feature, an algorithm to optimized a route algorithm, and several other minor additional features as potential means to shorten glances to the level comparable to that of conventional IP tasks.

Among the conventional IP tasks, three were found to exert high VADs on drivers: setting a cruise control, adjusting power mirrors, and manual tuning of a radio. The cruise control task involved manipulation of stalk-mounted controls, which were investigated by Mourant et al. (1977), and the author felt that because this task was normally performed in multi-lane limited access highway driving which exerted the lowest attentional demand, the high VAD associated with this task was "probably acceptable." Similarly, so long as drivers did not adjust mirrors while driving, the high VAD associated with the task would be of marginal concern. The high VAD of manually tuning a radio was in agreement with the results of other studies and of greater concern than the other two tasks, which were more of convenience options and not as commonly found in automobiles as a

Table 3. Task completion time means for each IP task (Dingus, 1987)

Task	Time from first glance (TIMEGLANCE)		Time from button press (TIMEST)	
	$\bar{x}$	SD	$\bar{x}$	SD
Turn Signal	0.64	0.68	0.62	0.71
Speed	1.19	0.98	1.07	0.81
Time	1.40	0.99	1.36	0.84
Following Traffic	1.45	0.99	1.30	0.78
Destination Direction	1.99	1.28	1.99	1.29
Remaining Fuel	2.04	1.33	1.99	1.24
Vent	2.35	2.76	2.13	1.59
Info. Lights	2.53	1.52	2.24	1.35
Destination Distance	2.58	1.70	2.34	1.56
Tone Controls	2.65	1.65	2.57	1.51
Fan	2.80	2.02	2.54	1.74
Cassette Tape	3.43	2.68	5.24	2.49
Defrost	3.89	2.40	3.56	2.12
Correct Direction	3.93	2.69	3.72	2.54
Balance	4.07	2.26	3.73	2.19
Sentinal	4.11	2.93	3.68	2.59
Fuel Economy	4.02	1.68	3.82	1.55
Fuel Range	4.21	1.81	3.95	1.60
Temperature	5.19	2.71	4.89	2.55
Zoom Level	5.64	3.43	5.27	3.31
Heading	5.62	4.16	5.72	4.11
Power Mirror	10.73	5.35	10.65	5.23
Cruise Control	10.47	7.30	11.88	7.96
Cross Street	11.59	7.41	11.08	7.50
Roadway Distance	13.23	8.11	13.04	7.84
Tune Radio	13.24	6.38	13.18	6.40
Roadway Name	16.04	10.22	15.87	10.26

Table 4. Total glance to IP means for each IP task (Dingus, 1987)

Task	Display Glance Time (Mean)	Standard Deviation
Turn Signal	0.38*	0.56
Speed	0.78	0.65
Following Traffic	0.98	0.60
Time	1.04	0.56
Vent	1.13	0.99
Destination Direction	1.57	0.94
Remaining Fuel	1.58	0.95
Tone Controls	1.59	1.03
Info. Lights	1.75	0.93
Destination Distance	1.83	1.09
Fan	1.95	1.29
Balance	2.23	1.50
Sentinal	2.38	1.71
Defrost	2.86	1.59
Fuel Economy	2.87	1.09
Correct Direction	2.96	1.86
Fuel Range	3.0	1.43
Temperature	3.50	1.73
Cassette Tape	1.59 + 1.64**	0.96 (0.59)**
Heading	3.58	2.23
Zoom Level	4.00	2.17
Cruise Control	4.82	3.80
Power Mirror	5.71	2.78
Tune Radio	7.6	3.41
Cross Street	8.63	4.86
Roadway Distance	8.84	5.20
Roadway Name	10.63	5.80

\* Drivers often did not glance at the turn signal lever, resulting in the low value of mean glance time.

\*\* Time required to search for and orient cassette tape.

Table 5. Number and average length of glances to IP means (Dingus, 1987)

Task	(DISAVE) Display single glance length		(DGLANCE) Number of glances	
	$\bar{x}$	SD	$\bar{x}$	SD
Turn Signal	0.30*	0.39	0.63*	0.73
Speed	0.62	0.48	1.26	0.40
Following Traffic	0.75	0.36	1.31	0.57
Time	0.83	0.38	1.26	0.46
Vent	0.62	0.40	1.83	1.03
Destination Direction	1.20	0.73	1.31	0.62
Remaining Fuel	1.04	0.50	1.52	0.71
Tone Controls	0.92	0.41	1.73	0.82
Info. Lights	0.83	0.35	2.12	1.16
Destination Distance	1.06	0.56	1.73	0.93
Fan	1.10	0.48	1.78	1.00
Balance	0.86	0.35	2.59	1.18
Sentinal	1.01	0.47	2.51	1.81
Defrost	1.14	0.61	2.51	1.49
Fuel Economy	1.14	0.58	2.48	0.94
Correct Direction	1.45	0.67	2.04	1.25
Fuel Range	1.19	1.02	2.54	0.60
Temperature	1.10	0.52	3.18	1.66
Cassette Tape	0.80	0.29	2.06	1.29
Heading	1.30	0.56	2.76	1.81
Zoom Level	1.40	0.65	2.91	1.65
Cruise Control	0.82	0.36	5.88	2.81
Power Mirror	0.86	0.34	6.64	2.56
Tune Radio	1.10	0.47	6.91	2.39
Cross Street	1.66	0.82	5.21	3.20
Roadway Distance	1.53	0.65	5.78	2.85
Roadway Name	1.63	0.80	6.52	3.15

\* Drivers often did not glance at the turn signal, causing the resulting low values.

Table 6. Average length of glances to the roadway means (Dingus, 1987)

<u>Task</u>	$\bar{x}$	SD
Following Traffic	0.37	0.49
Remaining Fuel	0.37	0.60
Fan	0.52	0.69
Time	0.24	0.41
Info. Lights	0.52	0.65
Speed	0.32	0.52
Fuel Range	0.53	0.39
Fuel Economy	0.57	0.48
Tone Controls	0.65	0.64
Defrost	0.54	0.56
Balance	0.82	0.63
Sentinal	0.76	0.85
Tune Radio	0.71	0.37
Vent	0.60	0.69
Temperature	0.59	0.41
Cassette Tape	0.90	0.48
Power Mirror	0.75	0.39
Heading	0.74	0.55
Destination Distance	0.40	0.52
Destination Direction	0.33	0.58
Roadway Name	0.65	0.44
Zoom Level	0.54	0.39
Roadway Distance	0.63	0.52
Cross Street	0.54	0.51
Correct Direction	0.58	0.74

**Table 7. Task grouping by cluster analysis (Dingus, 1987)**

**In the order of increasing visual attentional demand**

---

1. Adjust Vent; Check Speed; Check Time; Check for following traffic
  2. Adjust Balance; Adjust Sentinel; Adjust Tone; Check Information lights  
Point Destination Direction<sup>1</sup>; Determine Distance to Destination<sup>1</sup>  
Turn on Fan<sup>3</sup>; Check Remaining Fuel<sup>2</sup>
  3. Insert cassette tape
  4. Adjust Temperature<sup>3</sup>; Correct Direction<sup>1</sup>; Set Zoom level<sup>1</sup>; Determine Vehicle  
Heading<sup>1</sup>  
Turn on Defrost<sup>3</sup>; Check Fuel Economy<sup>2</sup>; Check Fuel Range<sup>2</sup>
  5. Adjust Power Mirrors; Tune Radio
  6. Set Cruise control
  7. Determine Cross street<sup>1</sup>; Determine Roadway Distance<sup>1</sup>; Determine Roadway Name<sup>1</sup>
- 

<sup>1</sup> ETAK navigator tasks

<sup>2</sup> Fuel data center tasks

<sup>3</sup> Electronic climate control tasks

radio. However, advances in consumer electronics have introduced such features as frequency scan and station seek which make manual tuning unnecessary. As the increasing number of radios comes equipped with these features, this concern, too, may become a moot point.

Lastly, gender and driving experience were found to have no significant effect on driver performance, while significantly longer task completion and total glance time, longer average length of glances to IP, greater number of errors, and longer brake actuations were observed among the 50+ years of age group (no statistically significant difference was found among the other three age groups). The number of glances and total glance time to IP were significantly less on a 4-lane limited highway than on the other two road types, while the average length of glances to IP was significantly shorter on a 2-lane state road.

#### *Imbeau (1987)*

The purpose of this study which was conducted in the moving-base driving simulator at Virginia Polytechnic Institute and State University (Appendix G) was to determine the dashboard illumination color(s) most suitable for nighttime driving on the basis of objective performance and subjective rating measures. The independent variables that were investigated were (1) hue (8 colors), (2) luminance (2 levels), (3) character size (4 sizes: 7, 11, 17, and 25 arc minutes in height at eye), and (4) word complexity (2 levels), while subjects were categorized by age (19 - 30, 31 - 50, and 51 - 73 years) and gender.

In the preliminary testing, two luminance levels were determined for each color by asking sixteen subjects (8 each gender; younger and older age groups of 8 each) to set "subjectively comfortable brightness." Median values for each age group were then used as the two levels (younger for low and older for high) of luminance in the main experiment.

Twenty-four subjects (4 for each combination of age and gender) performed a word reading task while driving the simulator in the main experiment. Stimulus slides were presented by two slide

projectors which were mounted on both sides of the simulator dashboard. The dependent variables in this experiment were:

- Objective performance measures
  1. Response time (correct response)
  2. Response time (any response)
  3. % correct response
  4. Total glance time (to slide projectors)
  5. Lane deviation variance
  
- Subjective ratings
  1. Attractiveness
  2. Comfort
  3. Ease of reading

The response times, which were the times between presentation of a stimulus and when subjects spoke a response, were measured real-time by a voice operated logic interfaced with a microcomputer (in case of no response within 8 seconds, the response time was recorded to be 8 seconds), while the total glance time was measured real-time by an experimenter who monitored driver's eye movements through a low light level camera mounted above and behind the dashboard in the simulator. The subjective ratings were collected verbally from each subject following the simulator session.

Gender had no significant effect on the performance measures, while the effect of age was significant on all six performance measures. The response times and % correct response were significantly longer and lower for the older age group, and the total glance time was significantly shorter for the younger age group (Figure 6).

RTCNO: time to a correct response

GTCNO: glance time for a correct response

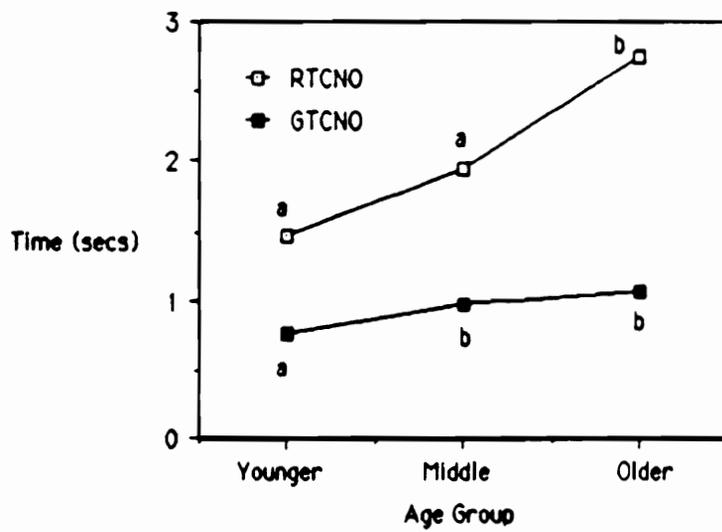


Figure 6. Response (correct) and glance times (Imbeau, 1987): Effect of age group

The subjective ratings showed (1) warm red, white, ochre and amber as the most attractive color (light blue was the least attractive) and (2) white as the easiest to read and light blue as the most difficult. With respect to subjective comfort, there was no difference among the eight colors. Neither was there a significant difference in terms of the objective performance measures.

Luminance was found to have significant effects on all six performance measures. Under the low luminance condition, the total glance and response times were longer, and there were more lane deviations. The high luminance level was also perceived to be more attractive and comfortable. Similarly, character size had significant effects on the six performance measures (Figure 7). A significantly lower response accuracy was recorded with the smallest (7 arc minute) size (there was no significant difference among the other three sizes), and the response times were significantly longer for the two smaller sizes (7 and 11 arc minutes).

Examinations of significant interactions showed that the performance was poorest, i.e., longest response time and fewest correct response, with stimuli in the small character size (7 arc minutes) under the low luminance condition. The performance degradation due to the small character size was also greater for the older subjects (Figure 8).

Based on these results, the author concluded the character size to be the most important factor and that the smallest (7 arc minute) size characters should not be used in the automotive IP labelling (the 11 arc minute size should be used sparingly and only under a high luminance level). Lastly, significant effects of word complexity were found in response and total glance times. The total glance time was particularly longer when higher complexity words were shown in the small character size. The author added that so long as the small character size was not used, the effect of word complexity was of secondary importance.

RTCNO: time to a correct response

GTCNO: glance time for a correct response

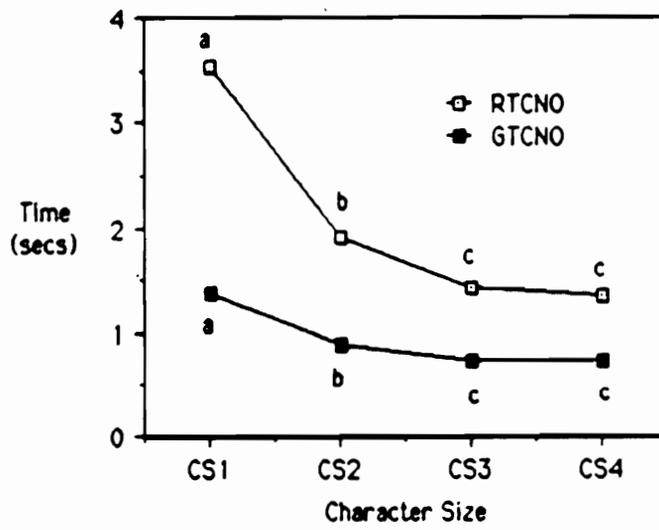


Figure 7. Response (correct) and glance times (Imbeau, 1987): Effect of character size

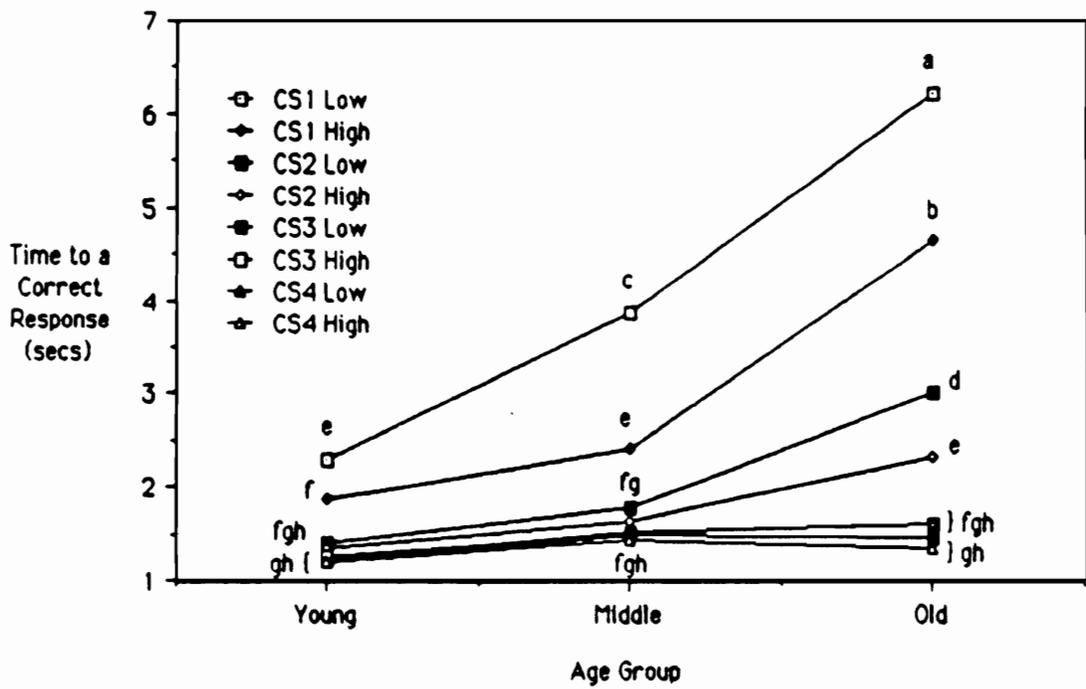


Figure 8. Response time (correct response) (Imbeau, 1987): Luminance x character size x age group interaction

*Hayes, Kurokawa, and Wierwille (1988)*

This in-car, on-road study was the first part of a multi-year research effort, of which this research program forms the concluding parts. The objectives of this project were (1) to characterize attentional demands of automotive instruments, (2) to develop a methodology to measure their attentional demands, then (3) to investigate a variety of factors which influence the demands, specifically VAD and CMD, through a comprehensive review of previous studies and a series of experiments and finally (4) to develop a methodology to evaluate contemporary and future automotive IP designs on the basis of their attentional demands. (The ultimate extension of this research effort would be to develop a theoretical model of driver IP task performance.) The objective of this study was thus to collect basic information about the VAD and CMD of a variety of automotive instruments and generic controls in the real driving environment.

Twenty-four subjects who were categorized (into cells of 2 each) by gender, age (18 - 25, 26 - 48, and 49 - 72), and driving experience (under and over 10,000 miles driven annually) drove an instrumented 1985 Cadillac Sedan deVille through four types of preselected routes (4-lane limited access highway, 2-lane rural road, city/town streets, and residential streets) while performing a variety of IP tasks. While subjects performed a task, a concurrent driving workload was determined (in three levels) by an experimenter.

The research vehicle was equipped with a digital dashboard, electronic climate control, cruise control, power mirrors, and a fuel data center. Its steering wheel was modified with a Pontiac hub-mounted pushbutton control center to provide 12 steering-wheel-mounted buttons. An auxiliary IP (Figure 9), which consisted of a 12-button telephone keypad, a 16-segment LED bar display, an AM/FM radio/cassette player with a deflection knob and a digital display for tuning, 4- and 9-position rotary knobs, another AM/FM radio/cassette player with a continuous knob and an analog pointer for tuning and a 3-band graphic equalizer, a 3x5 array of pushbuttons, and another Pontiac pushbutton control center, was also used to provide additional IP tasks. During each data collection session, the auxiliary IP was mounted in four different positions (either in line with or

below the dashboard of the car, and either parallel to the car's lateral axis or angled toward the driver). There were a total of 58 distinct types of IP tasks (task categories) which were performed in this study.

The dependent variables measured in this study were:

1. Task completion time
2. Total hand-off-wheel time
3. Number of glances to the roadway, IP, and other
4. Average length of glances to the roadway, IP, and other
5. Average length and number of eye transitions
6. Number and average duration of lane exceedance

While the task completion and hand-off-wheel times were measured real-time by the experimenters (and stored by an on-board IBM PC microcomputer), eye glance and lane deviation measures were recorded by hood- and roof-mounted videocameras and determined after the data collection session. The eye glance measures, in particular, were analyzed frame-by-frame by custom electronics developed by Dr. W. W. Wierwille. As the videocamera recorded 30 frames per second, this method provided a temporal resolution of 0.033 seconds and allowed a greater precision in determining the length of each glance than in the previously reported studies. Since any observation in which subjects made an error was repeated during the data collection session, no record of the error was kept and all data points were for a successful task completion.

An overall analysis of IP task performance measures found significant effects of age, gender, road type, concurrent driving workload, and position of an instrument for the task in IP. The age group was found to have significant effects on task completion and hand-off-wheel times, the number of glances to IP, glances to the roadway, and transitions (the latter two glance frequency measures were mostly redundant with the number of glances to IP), and the average length of transitions. A monotonical increase in task completion time and the number of glances to IP was observed

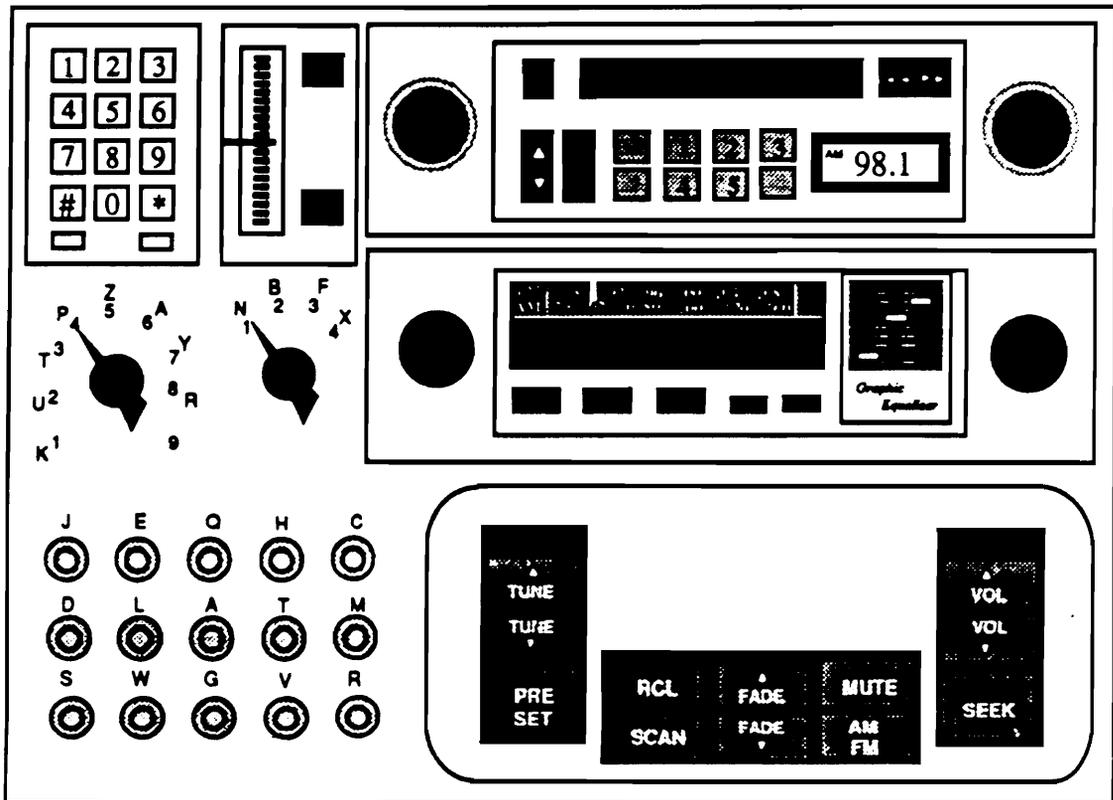


Figure 9. Auxiliary instrument panel

with age, and the differences among the three age groups were significant. The average length of transitions was significantly longer for the older age group, suggesting greater difficulty in accommodation and locating a desired point in IP. A significant difference in the number of glances to IP was also found between genders: the female group making more glances than the male. Evidently, this difference by gender became larger as age increased.

The road type had a significant effect (only) on the average length of glances to IP, and significantly longer glances were made on the town streets than on the city/town streets and 2-lane rural road. The concurrent driving workload, on the other hand, had significant effects on all dependent measures except the average length of eye transitions. The task completion time and the average length of glances to the roadway were significantly longer under the high workload conditions (no significant difference between the low and medium), while significant differences among the three workload levels were found in the number of glances to IP (its average length was significantly longer under the low workload condition).

The position in the IP, where the instrument used for the specified task is located, had a significant effect on the average length of transitions. The transition times obviously increased with the distance from the driver's forward line of sight, to the roadway. The fastest transitions were thus made to and from the center of the dashboard, followed by the steering wheel and side locations of the dashboard (significantly longer than the center location, but about the same among these locations). The longest transitions were made to instruments on the auxiliary IP mounted in the below-dashboard (console) positions.

Means for IP task categories in task completion time, total glance to IP, and the number and average length of glances to IP were rank-ordered (Tables 8 and 9).

**Table 8. Task category means (Hayes, Kurokawa, and Wierwille, 1988)**

TASK DESCRIPTION		DISPLAY		TOTAL	
		TOTAL GLANCE		TASK	
		TIME		TIME	
		MEAN	S.D.	MEAN	S.D.
TRNSIG	TURN SIGNAL (CONVENTIONAL)	0.35	0.96	1.87	1.15
RDSPED	READ DIGITAL SPEEDOMETER	1.06	0.31	2.05	0.5
MAPLIT	SINGLE OVERHEAD PB	1.18	0.60	3.48	2.71
PSHDIR	DIRECTIONAL PB ("BOTTOM LEFT")	1.19	0.57	2.58	1.63
STR103	1 OF 3 PB. STEERING WHEEL HUB (FTN LABELS)	1.24	0.83	2.60	1.87
PSH103	1 OF 3 PB. PANEL (RANDOM LETTERS)	1.61	0.85	3.28	1.93
BOT103	1 OF 3 PB. PONTIAC ON PANEL (FTN LABELS)	1.62	1.10	3.64	2.33
TOP105	1 OF 5 PB. TOP RADIO (NUMBERED)	1.64	0.89	3.12	1.55
STR106	1 OF 6 PB. STEERING WHEEL HUB (FTN LABELS)	1.70	1.68	3.04	2.57
GREQLA	GRAPH. EQ., LOW ACCURACY	1.71	1.58	3.65	3.23
RT104S	1 OF 4. ROTARY SELECTOR (SEQUENTIAL)	1.72	0.95	3.08	1.74
PSH105	1 OF 5 PB. PANEL (RANDOM LETTERS)	1.73	1.94	4.25	3.90
TELPH1	PRESS 1 OF 2 PB (FTN LABELS)	1.82	0.94	3.28	1.50
LEDCST	BAR LED. AUTO. SET NUMBER OF STEPS	1.85	1.06	4.04	2.20
TOPMSC	MEMORY SCAN. TOP RADIO. PUSH KNOB	1.91	1.43	3.73	2.64
RT104R	1 OF 4. ROTARY SELECTOR (RANDOM LETTERS)	1.91	1.04	3.51	2.28
WINDOW	ADT. WINDOW. 1 OF 4 ROCKERS. DOOR	1.96	1.54	4.98	3.05
STR112	1 OF 12 PB. STEERING WHEEL HUB (FTN LABELS)	1.99	1.27	3.51	2.15
TOPEJT	EJECT CASSETTE. TOP RADIO. SINGLE PB	2.01	1.07	5.45	2.45
PSH115	1 OF 15 PB. PANEL (RANDOM LETTERS)	2.09	1.00	3.74	1.64
BOT106	1 OF 6 PB. PONTIAC ON PANEL (FTN LABELS)	2.12	1.52	4.13	2.28
GREQHA	GRAPH. EQ., HIGH ACCURACY	2.16	1.41	4.62	2.86
RSODOM	RESET TRIP ODOMETER (SINGLE PB)	2.19	1.10	3.79	1.67
LEDDST	BAR LED. MANUAL. SET NUMBER OF STEPS	2.20	1.39	3.97	1.76
PSH205	2 OF 5 PB. PANEL (RANDOM LETTERS)	2.29	1.31	4.10	2.97
SENTIN	DASH SENTINELS (1 OF 2 HORIZ. SLIDES)	2.35	1.99	5.62	3.04
VOLUME	CONTINUOUS ROTARY KNOB	2.36	1.94	5.07	2.97
RT109S	1 OF 9. ROTARY SELECTOR (SEQUENTIAL)	2.37	1.28	4.22	2.12
PSH203	2 OF 3 PB. PANEL (RANDOM LETTERS)	2.40	2.19	4.75	4.08
RDODOM	READ ODOMETER	2.42	1.19	4.48	2.38

Table 8 (continued)

TASK DESCRIPTION	DISPLAY		TOTAL		
	TOTAL GLANCE		TASK		
	TIME		TIME		
		MEAN	S.D.	MEAN	S.D.
BOT112	1 OF 12 PB. PONTIAC ON PANEL (FTN LABELS)	2.44	1.44	4.65	2.51
RVMIRR	ADJUST REAR VIEW MIRROR	2.49	0.90	5.04	1.87
PULBAL	BALANCE. PULL. AND ROTATE W/CENTER DETENT	2.65	1.74	6.25	3.09
RT109R	1 OF 9. ROTARY SELECTOR (RANDOM LETTERS)	2.67	1.47	4.64	2.51
MID103	1 OF 3. HORIZONTAL PB (FTN LABELS)	2.71	1.82	4.98	3.14
BOT212	2 OF 12 PB. PONTIAC ON PANEL (FTN LABELS)	2.73	1.41	5.20	1.75
STR212	2 OF 12 PB. STEERING WHEEL HUB (FTN LABELS)	2.76	1.27	5.08	2.31
ROTBAL	BALANCE. ROTATE WITH CENTER DETENT	2.90	2.02	6.36	3.26
LEDCLA	BAR LED. AUTO. LOW ACCURACY	3.02	1.27	5.23	2.27
TOP104	1 OF 4 PB. TOP RADIO (FTN LABELS)	3.09	2.08	5.42	3.47
LEDDLA	BAR LED. MANUAL. LOW ACCURACY	3.17	1.29	5.20	2.22
TOPCAS	INSERT CASSETTE. TOP RADIO	3.39	1.82	7.65	3.13
DAS105	1 OF 5 PB. DASHBOARD	3.65	2.50	5.98	4.18
TOPFFR	FAST FORW/REV. 1 OF 2 PB. ARROW LABELS	3.67	2.37	6.38	3.49
LEDDHA	BAR LED. MANUAL. HIGH ACCURACY	3.69	1.64	6.33	3.20
TELPH4	4 DIGITS. TELEPHONE KEYPAD	3.79	1.07	6.61	1.21
LEDCHA	BAR LED. AUTO. HIGH ACCURACY	4.12	2.40	6.44	3.69
DAS104	1 OF 4 PB. DASHBOARD (FTN LABELS)	4.19	2.16	6.52	3.40
TOPTIM	BUTTON PRESS. READ TIME	4.66	2.17	7.34	3.94
STR312	3 OF 12 PB. STEERING WHEEL (FTN LABELS)	4.70	4.02	7.55	6.44
TELPH7	PRESS "*", A 7-DIGIT NUMBER. THEN "#"	5.64	2.96	9.02	3.96
MIDOTV	TURN ON. MANUAL TUNE (ANALOG) INCREASE VOL	5.85	2.85	10.86	5.36
PSH315	3 OF 15 PB. PANEL (RANDOM LETTERS)	6.05	4.09	9.96	6.35
SDMIRR	ADJ. SIDE MIRROR (L,R). 4 PB (ARROWS)	6.20	3.80	12.70	7.91
TELPH11	PRESS "*", AN 11-DIGIT PHONE NO., THEN "#"	6.67	1.90	10.91	3.45
MIDAMT	PRESS AMFM. MANUAL TUNE (ANALOG)	6.97	3.29	11.80	5.46
TOPOTV	TURN ON. MANUAL TUNE (DIG) INCREASE VOL	10.10	7.70	18.18	10.92
TOPAMT	PRESS AMFM. MANUAL TUNE (DIGITAL)	11.76	5.97	19.32	8.78

**Table 9. Task category means (Hayes, Kurokawa, and Wierwille, 1988)**

TASK DESCRIPTION	DISPLAY		NUMBER	
	SINGLE GLANCE		OF	
	TIME		GLANCES	
	MEAN	S.D.	MEAN	S.D.
TRNSIG TURN SIGNAL (CONVENTIONAL)	0.28	0.81	0.35	0.60
RDSPED READ DIGITAL SPEEDOMETER	0.93	0.33	1.20	0.41
MAPLIT SINGLE OVERHEAD PB	0.84	0.42	1.50	0.72
PSHDIR DIRECTIONAL PB ("BOTTOM LEFT")	1.01	0.42	1.20	0.45
STR103 1 OF 3 PB, STEERING WHEEL HUB (FTN LABELS)	0.91	0.46	1.41	0.90
PSH103 1 OF 3 PB, PANEL (RANDOM LETTERS)	1.13	0.39	1.52	1.03
BOT103 1 OF 3 PB, PONTIAC ON PANEL (FTN LABELS)	1.09	0.55	1.59	1.05
TOP105 1 OF 5 PB, TOP RADIO (NUMBERED)	1.20	0.37	1.44	0.81
STR106 1 OF 6 PB, STEERING WHEEL HUB (FTN LABELS)	1.04	0.42	1.67	1.38
GREQLA GRAPH. EQ., LOW ACCURACY	1.14	0.44	1.49	1.02
RT104S 1 OF 4, ROTARY SELECTOR (SEQUENTIAL)	1.14	0.47	1.59	0.89
PSH105 1 OF 5 PB, PANEL (RANDOM LETTERS)	1.01	0.43	1.81	2.02
TELPH1 PRESS 1 OF 2 PB (FTN LABELS)	1.35	0.53	1.44	0.68
LEDCST BAR LED, AUTO, SET NUMBER OF STEPS	1.11	0.49	1.70	0.87
TOPMSC MEMORY SCAN, TOP RADIO, PUSH KNOB	1.16	0.55	1.63	1.06
RT104R 1 OF 4, ROTARY SELECTOR (RANDOM LETTERS)	1.25	0.46	1.65	0.98
WINDOW ADT. WINDOW, 1 OF 4 ROCKERS, DOOR	0.73	0.28	2.56	1.38
STR112 1 OF 12 PB, STEERING WHEEL HUB (FTN LABELS)	1.10	0.44	1.84	1.10
TOPEJT EJECT CASSETTE, TOP RADIO, SINGLE PB	0.98	0.58	2.17	0.96
PSH115 1 OF 15 PB, PANEL (RANDOM LETTERS)	1.37	0.59	1.68	0.95
BOT106 1 OF 6 PB, PONTIAC ON PANEL (FTN LABELS)	1.25	0.61	1.74	0.97
GREQHA GRAPH. EQ., HIGH ACCURACY	1.10	0.44	1.96	1.02
RSODOM RESET TRIP ODOMETER (SINGLE PB)	0.96	0.34	2.29	0.90
LEDDST BAR LED, MANUAL, SET NUMBER OF STEPS	1.14	0.57	1.94	0.97
PSH205 2 OF 5 PB, PANEL (RANDOM LETTERS)	1.30	0.65	2.03	1.36
SENTIN DASH SENTINELS (1 OF 2 HORIZ. SLIDES)	1.07	0.43	2.27	1.84
VOLUME CONTINUOUS ROTARY KNOB	1.16	0.50	2.01	1.25
RT109S 1 OF 9, ROTARY SELECTOR (SEQUENTIAL)	1.19	0.47	2.15	1.03
PSH203 2 OF 3 PB, PANEL (RANDOM LETTERS)	1.10	0.37	2.23	1.87
RDODOM READ ODOMETER	1.37	0.71	2.06	1.17

Table 9 (continued)

TASK DESCRIPTION	DISPLAY		NUMBER	
	SINGLE GLANCE		OF	
	TIME		GLANCES	
	MEAN	S.D.	MEAN	S.D.
BOT112 1 OF 12 PB. PONTIAC ON PANEL (FTN LABELS)	1.23	0.42	2.06	1.15
RVMIRR ADJUST REAR VIEW MIRROR	0.92	0.43	3.17	1.55
PULBAL BALANCE, PULL, AND ROTATE W/CENTER DETENT	1.14	0.50	2.38	1.38
RT109R 1 OF 9, ROTARY SELECTOR (RANDOM LETTERS)	1.36	0.48	2.17	1.20
MID103 1 OF 3, HORIZONTAL PB (FTN LABELS)	1.35	0.49	2.06	1.24
BOT212 2 OF 12 PB. PONTIAC ON PANEL (FTN LABELS)	1.23	0.71	2.54	1.38
STR212 2 OF 12 PB, STEERING WHEEL HUB (FTN LABELS)	1.19	0.45	2.50	1.18
ROTBAL BALANCE, ROTATE WITH CENTER DETENT	1.30	0.54	2.38	1.81
LEDCLA BAR LED, AUTO. LOW ACCURACY	1.17	0.54	2.88	1.27
TOP104 1 OF 4 PB, TOP RADIO (FTN LABELS)	1.49	0.49	2.25	1.62
LEDDLA BAR LED, MANUAL, LOW ACCURACY	1.33	0.61	2.67	1.13
TOPCAS INSERT CASSETTE, TOP RADIO	0.86	0.33	4.00	1.53
DAS105 1 OF 5 PB, DASHBOARD	1.50	0.73	2.74	1.81
TOPFFR FAST FORW/REV, 1 OF 2 PB, ARROW LABELS	1.45	0.48	2.65	1.59
LEDDHA BAR LED, MANUAL, HIGH ACCURACY	1.24	0.57	3.42	2.09
TELPH4 4 DIGITS, TELEPHONE KEYPAD	1.32	0.68	3.25	1.07
LEDCHA BAR LED, AUTO, HIGH ACCURACY	1.43	0.57	3.16	1.78
DAS104 1 OF 4 PB, DASHBOARD (FTN LABELS)	1.31	0.50	3.31	1.70
TOPTIM BUTTON PRESS, READ TIME	1.41	0.49	3.54	1.86
STR312 3 OF 12 PB, STEERING WHEEL (FTN LABELS)	1.20	0.54	4.08	3.26
TELPH7 PRESS *, A 7-DIGIT NUMBER, THEN #	1.41	0.62	4.27	1.76
MIDOTV TURN ON, MANUAL TUNE (ANALOG) INCREASE VOL	1.36	0.65	4.75	2.27
PSH315 3 OF 15 PB, PANEL (RANDOM LETTERS)	1.54	0.72	4.29	2.50
SDMIRR ADJ. SIDE MIRROR (L,R), 4 PB (ARROWS)	0.80	0.25	8.00	4.31
TELPH11 PRESS *, AN 11-DIGIT PHONE NO., THEN #	1.23	0.52	5.65	1.94
MIDAMT PRESS AMFM, MANUAL TUNE (ANALOG)	1.33	0.58	5.50	2.41
TOPOTV TURN ON, MANUAL TUNE (DIG) INCREASE VOL	1.15	0.40	8.75	5.17
TOPAMT PRESS AMFM, MANUAL TUNE (DIGITAL)	1.28	0.46	9.17	3.81

## Summary

The driver IP task performance studies which were reviewed in this chapter might be categorized into three groups on the basis of the scope(s) of their investigations. The first group (Anacapa Sciences, 1976; Malone, Krumm, Shenk, and Kao, 1972; Mourant, Moussa-Hamouda, and Howard, 1977) dealt with conventional automotive instruments. Contemporary arrangements and control types were surveyed, and driver performances using these instruments were compared with each other. One finding was that driver expectancy was an important factor in determining the performance during an initial period of use (the effect decreased with learning). It is then expedient to consider conventions and trends which influence the expectancy in IP designs.

The second group of studies (Dingus, 1987; Heintz et al., 1982, 1985; Monty, 1984; Rockwell, 1983) examined new technology instruments, e.g., electronic navigation aid, general-purpose trip computer, and touch panel displays, and compared the driver task performance of these instruments to conventional instruments. Using the conventional IP task performance as the yardstick, these studies provided useful evaluations of emerging technology. The third and most recent group of studies (Hayes, Kurokawa, and Wierwille, 1988; Imbeau, 1987) went a step further and examined certain conceptual issues within the context of present IP designs.

One might conclude that the studies to date have taken only a few steps in this process of searching for means to evaluate automotive IP designs. The first step was to recognize the importance of issues concerning IP designs. Motivations certainly do exist to support research in this area; not an urge, however. The second group of studies perhaps represented the second step which was to define and implement appropriate measures to assess the driver IP task performance. Despite the certain lack of consistency that exists among the studies, it appears that the task completion measures and visual attentional demand (VAD) measures based on driver eye movements are feasible and appropriate for the purpose.

The third step being taken is then to define pertinent factors, present and future, and to determine their effects and interactions on those performance measures. Steps yet to be taken are to achieve a better understanding of the driver IP task performance such that absolute performance standards can be established. Then, if the current conventions are judged inadequate, the true optimum based on the performance measures (and other human factors principles) might perhaps be defined and redefine what are to be the new conventions. Of course, expanded knowledge of theoretical issues influencing the driver IP task performance will contribute to the overall understanding of underlying mechanisms in the act of driving.

This research program thus attempts to advance the present state of knowledge and to develop an initial model, however rudimentary it may be, of driver IP task performance based on available information.

## RESEARCH OBJECTIVES

Following are the specific objectives which this research program proposes to achieve:

1. Perform a comprehensive review of available research on automotive IP task performance
2. Conduct three driving simulator experiments to collect additional data on conventional IP tasks and investigate issues pertinent to the IP design that have not been examined previously
3. Extract all relevant information on automotive instrument VAD, CMD, and other task performance measures from the findings of objectives 1 and 2
4. Compile all available data into a computerized data base and integrate the data into a computerized model, which will allow interpolation of values for conditions for which no data are available (Empirical model)
5. Develop computerized procedures for estimating driver performance measures for types of IP tasks without prior data (Estimation procedures)

At its conclusion, this research program will contribute in two ways:

- Provide evaluation aids to the automotive design community for improved IP designs
- Provide specific suggestions to the human-machine interface research community regarding the direction of future investigations

## DRIVING SIMULATOR EXPERIMENTS

A series of experiments was conducted in the moving-base driving simulator at Virginia Polytechnic Institute and State University, in which driving conditions could be set precisely and repeatedly, to expand the data base created by Hayes et al. (1988) and to investigate additional factors not previously studied. In these experiments, large amounts of data in the conventional IP tasks were gathered under different simulated driving conditions.

The first in-simulator experiment was intended to "calibrate" the driving workload of the simulator to that encountered in the Hayes et al. (1988) in-car, on-road study, so that the findings from the driving simulator studies would be representative of the real driving environment. Specifically, data were collected on a group of task categories selected from the Hayes et al. (1988) study under

- one static condition, where subjects performed tasks without driving, and
- four dynamic conditions, corresponding to four levels of random crosswind, where subjects performed tasks while driving.

The data gathered under the static condition were to provide the base-line performance when IP tasks are the only, and thus primary, task and to be compared with data from the dynamic conditions and also with those from the in-car study to be tested for correlations. The effect of random crosswind was examined to determine the level which would produce the driving workload that best simulates the real driving conditions.

In the second in-simulator experiment, the effect of IP macroclutter on task performance, i.e., how the number of instruments contained in the dashboard influenced driver performance, was investigated. Prototype panels with four levels of macroclutter were presented to subjects, and data were collected under a static condition and two dynamic simulator conditions (both without random crosswind). In this experiment, the IP task performance was examined under two types of simulated road conditions: on a straight roadway and with road curvature.

During the third in-simulator experiment, issues involving abbreviation of control labels, namely label ambiguity and (micro)clutter around the controls, within an instrument, were investigated. A CRT display was added to the dashboard to simulate a touch panel display, i.e., a visual display with a transparent touch sensitive entry device. The level of label abbreviation, as well as the number of controls, was varied in the simulated touch panel.

### Common method in the driving simulator experiments

#### *Experimental subjects*

Eight subjects (4 female and 4 male) who were students at Virginia Polytechnic Institute and State University participated in each experiment and were paid at the rate of \$5.00 per hour. After reading a brief description of the experiment (Appendix A) and signing the informed consent form (Appendix B), subjects' visual acuity was tested using a Titmus II vision tester. The selection criterion used in this study was the minimum acuity (either uncorrected or corrected by contact lenses) of 20/40 in both far and near visions (20/25 near vision required in Experiments 2 and 3). Subjects, all of whom were licensed drivers, also filled out a brief questionnaire (Appendix C) regarding their driving histories.

#### *Apparatus*

The moving-base driving simulator at the Vehicle Analysis and Simulation Laboratory (Appendix G) was programmed with the vehicle dynamics of a 1986 Cadillac C car. In addition to the base configuration of the driving simulator, special instrumentation was included in each experiment. Additional equipment employed in a specific experiment is described in the appropriate section.

**Auxiliary instrument panel** The auxiliary instrument panel which was used in the Hayes et al. (1988) in-car study was mounted on the right-hand side of the driving simulator dashboard (Figure 10). Its position relative to the driver was so adjusted to be identical to the low, angled position

in the in-car study. Briefly, the auxiliary IP (Figure 9) included a 12-button telephone keypad, a 16-segment LED bar display, a Sparkomatic SR350 AM/FM radio/cassette player, 4- and 9-position rotary knobs, a Kraco KGE-601 AM/FM radio/cassette player with a 3-band graphic equalizer, a 3x5 array of pushbuttons, and a Pontiac hub mounted pushbutton control center. During the experimental sessions the instrument panel was illuminated by additional lighting mounted on the simulator.

**Slide projector** A modified Kodak Medalist I carousel projector was mounted on the left-hand side of the driving simulator dashboard. The slide projector contained slides with words of varying size and complexity, which were used in Imbeau (1987). Slides were advanced by the front experimenter during the experimental sessions. Subjects viewed the slides in the projector directly. (The lens had been removed, and the projector lamp replaced with an incandescent lamp. The luminance and color remained constant.)

**Data collection system** Two experimenters were involved in each experimental session. The front experimenter who was seated to the right and behind the subject, beside the simulator lower platform, was assigned to provide the introduction to the simulator and instrument panel, to give task instructions and to time performance (Figure 11). The other experimenter, seated at the main control console, oversaw the operations of the data collection program, VCR, and the simulator. This experimenter also measured the hand-off-wheel time.

A TRS-80 Model III microcomputer with a custom interface was used to record the time between the end of a task instruction and when subjects completed the task, and the time during which subjects' hands were off the steering wheel. The front experimenter signaled when subjects initiated and completed each task by pressing a button on the custom control box, while the experimenter seated at the simulator console did the same for the hand-off-wheel time.

During the session, subject's eye movements were monitored by a low light level video camera mounted above and behind the right-hand side of the simulator dashboard and were recorded by

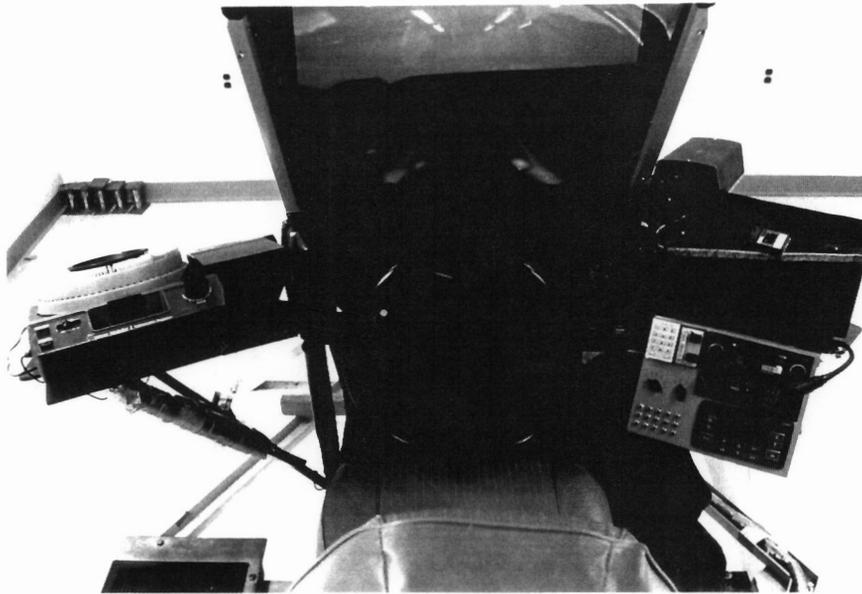


Figure 10. Auxiliary instrument panel mounted on the driving simulator

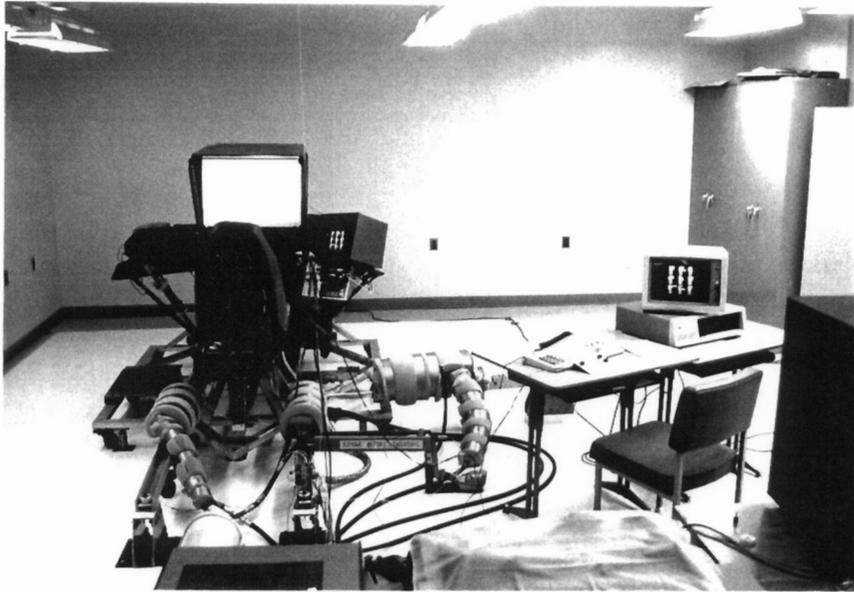


Figure 11. Driving simulator and experimenter stations

a VCR for later analyses. An LED indicator was also mounted on the dashboard and aimed at the camera so that a lit LED would be recorded on the video tape while a task was in progress. The VCR's audio channel was connected to the front experimenter's microphone to record his task instructions.

## Experiment 1: Simulator Validation for Conventional IP Tasks

### *Procedure (Experiment 1)*

Eight subjects (4 female and 4 male) with a median age of 21-1/2 years (ranging from 20 to 22; median number of years driving: 5-1/2) participated in this experiment. At the beginning of the session, subjects were seated in the driving simulator, and the operations of various controls on the auxiliary instrument panel (IP) were explained to them. Two static "runs" which followed the introduction were intended to familiarize subjects with the types of IP tasks which they would be instructed to perform, as well as to measure their task performance while not driving (Figure 12). (A detailed description of static runs is given below.)

Subjects then drove the simulator and were given several minutes to become familiar with its handling. The driving practice was provided with and without random crosswinds, and subjects also practiced performing tasks while driving.

Subject's task performance while driving was measured during four simulator runs (a detailed description of which is provided below), which were followed by another static run. At the end of an experimental session, subjects were debriefed and compensated for their participation. (Subject participation lasted about 1-1/2 hours.)

**Static simulator runs** Forty-one auxiliary instrument panel (IP) task categories which were included in the in-car study were used during the static runs (Table 10).

During each static run, one observation of each task category was made, and the ordering of tasks was randomized (Appendix D). Subjects were instructed to keep their hands on the steering wheel and their eyes on the roadway as if they were stopped at a traffic light. Their task completion times and hand-off-wheel times were measured. (Their eye movements were recorded on a VCR.)

## Experiment 1 Session Timeline

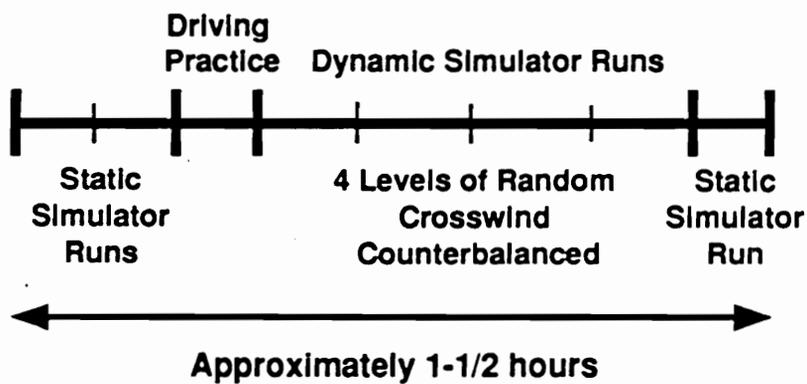


Figure 12. Experiment 1 Session Timeline

**Table 10. List of IP task categories**

<b>Task Category</b>	<b>Description</b>
Bot 1o3 <sup>123</sup>	Bottom (Pontiac) radio. Press one of three buttons.
Bot 1o6 <sup>123</sup>	Bottom (Pontiac) radio. Press one of six buttons.
Bot 1o12 <sup>123</sup>	Bottom (Pontiac) radio. Press one of twelve buttons.
Bot 2o12	Bottom (Pontiac) radio. Press two of twelve buttons.
LEDC High <sup>123</sup>	LED Continuous mode. High accuracy adjustment.
LEDC Low	LED Continuous mode. Low accuracy adjustment.
LEDC Step <sup>123</sup>	LED Continuous mode. Step-wise adjustment.
LEDD High	LED Discrete mode. High accuracy adjustment.
LEDD Low	LED Discrete mode. Low accuracy adjustment.
LEDD Step	LED Discrete mode. Step-wise adjustment.
MGE High <sup>123</sup>	Middle (Kraco) radio graphic equalizer. High accuracy adjustment.
MGE Low <sup>123</sup>	Middle (Kraco) radio graphic equalizer. Low accuracy adjustment.
Mid AMT <sup>2</sup>	Middle (Kraco) radio. Press FM/AM then tune.
Mid OTV	Middle (Kraco) radio. Turn on, tune, and adjust volume.
Mid 1o3	Middle (Kraco) radio. Press one of three buttons.
PB Directed <sup>123</sup>	Pushbutton array. Button location directed.
PB 1o3	Pushbutton array. Press one of three (column).
PB 1o5 <sup>13</sup>	Pushbutton array. Press one of five (row).
PB 1o15	Pushbutton array. Press one of fifteen.
PB 2o3	Pushbutton array. Press two of three (column).
PB 2o5	Pushbutton array. Press two of five (row).
PB 3o15	Pushbutton array. Press three of fifteen.
Pul Balance	Top (Sparkomatic) radio. Pull and turn balance.
Rot Balance	Middle (Kraco) radio. Turn balance.
RT 1o4R <sup>12</sup>	4-position rotary knob. Alphabet selection.
RT 1o4S <sup>123</sup>	4-position rotary knob. Numeral selection.
RT 1o9R	9-position rotary knob. Alphabet selection.
RT 1o9S <sup>123</sup>	9-position rotary knob. Numeral selection.

**Table 10 (Continued)**

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Telephone 1	Telephone keypad. Press a button.
Telephone 4	Telephone keypad. Dial 4 digits.
Telephone 7	Telephone keypad. Dial 9 digits.
Telephone 11 <sup>123</sup>	Telephone keypad. Dial 13 digits.
Top AMT <sup>23</sup>	Top (Sparkomatic) radio. Press AM/FM then tune.
Top CAS	Top (Sparkomatic) radio. Insert a cassette tape.
Top EJT	Top (Sparkomatic) radio. Eject a cassette tape.
Top FFR	Top (Sparkomatic) radio. Fast-forward or rewind.
Top OTV	Top (Sparkomatic) radio. Turn on, tune, and adjust volume.
Top Time <sup>23</sup>	Top (Sparkomatic) radio. Read present time.
Top 1o4 <sup>1</sup>	Top (Sparkomatic) radio. Press one of four buttons.
Top 1o5 <sup>123</sup>	Top (Sparkomatic) radio. Press one of five buttons.
Volume	Top (Sparkomatic) and middle (Kraco) radio. Adjust volume.

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<sup>1</sup> Included in the dynamic simulator portion of Experiment 1

<sup>2</sup> Included in the dynamic simulator portion of Experiment 2

<sup>3</sup> Included in the dynamic simulator portion of Experiment 3

The purpose of the static runs was threefold: (1) to familiarize subjects with the tasks during the two static runs preceding simulator runs, (2) to test the effect of practice/learning by comparing static runs before and after the simulator runs, and (3) to measure the base task performance when the operation of the instrument panel was the only task.

**Dynamic simulator runs** A 4 x 15 full factorial within-subject design using 8 subjects and 2 repeated measures per cell was utilized for the dynamic simulator runs. The independent variables were the level of random crosswind and task category.

Each of the four simulator runs consisted of two observations of 15 auxiliary IP task categories and several non-measured tasks, such as asking subjects to read the present vehicle speed and to read a word on a slide. The 15 IP task categories (Table 10) were selected on the basis of the relatively small variance in dependent measures exhibited during the Hayes et al. (1988) in-car study. (Their mean values were also spread over the range of task category means.)

The in-simulator measurements were run under four levels of random crosswind: no crosswind, 60, 120, and 180 pounds, RMS, applied laterally at the simulated vehicle's center of pressure. The random crosswind was generated by a low frequency random noise generator followed by a low pass filter, and its amplitude distribution was Gaussian and stationary. Each set of task instructions was assigned with one of the four levels of random crosswind. This matching of task instruction and crosswind was not considered to cause any bias, as task ordering was completely randomized (Appendix D).

The presentation order of crosswind levels was counterbalanced in such a way that should the presentation order have a significant effect on dependent measures, the data could then be reanalyzed as a 2 x 4 x 4 x 15 Latin square design. That is, a Latin square was repeated for each gender, while all combinations of the original two independent variables (crosswind and task category) were maintained in the Latin square.

The simulated roadway for the dynamic simulator measurements was a straight 2-lane roadway with no other vehicles in the scene. This decision was based on the finding in the in-car study that the road type had no significant effect on the task completion time, and the number and average length of glances to display.

To insure that subjects did not neglect driving and concentrate on performing the IP tasks, a lane deviation tone (called a "lane minder") was provided. The tone sounded whenever the simulated vehicle strayed from the assigned (right) lane of roadway. (The amplitude of tone was directly proportional to the extent of lane deviation, and as lane deviation became larger, the tone pulsed in amplitude.)

The video tape which recorded subject's eye movements while performing tasks was analyzed frame-by-frame after the experiment session, and the number and length of glances to roadway, to IP, to other points, and in transition were determined. Statistical analyses of these measures, as well as the task completion and hand-off-wheel times, were then performed using the Statistical Analysis System on the University's IBM 3090 computer.

### *Results (Experiment 1)*

**Dynamic simulator runs** The results of analyses of variance on five dependent measures (Task completion time, hand-off-wheel time, number of glances to display, average lengths of glances to roadway and to the auxiliary IP) are summarized in Table 11. Briefly, the observed values in each cell were averaged, and these cell means were used to perform the within-subject analyses.

The measures that were available from the eye movement analysis but not included in these analyses were (1) numbers of glances to roadway and in transition (which were closely related to the number of glances to IP and were thus considered redundant), (2) the total lengths of glances to the roadway, to IP, and in transition (which were approximately proportional to the numbers of glances to each respective area), and (3) the lengths of transitions (which were nearly constant for

Table 11. Analyses of variance summary (Experiment 1)

Probability values less than 0.05 are shown.

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Gender (G)	1				0.0035	
Crosswind (C)	3	0.0025		0.0166		0.0001
Task Category (T)	14	0.0001	0.0001	0.0001	0.0001	0.0001
G x C	3					
G x T	14					
C x T	42	0.0375			0.0001	
G x C x T	42	0.0072				

each subject). The five dependent measures which were included in these analyses were also used in the analyses of the in-car study.

The effect of random crosswind was found significant in three measures: task completion time ( $p = 0.0001$ ), average lengths of glances to the roadway ( $p = 0.0166$ ), and to IP ( $p = 0.0001$ ). The results of Newman-Keuls tests (Table 12) show that the task completion time and the average length of glances to the roadway increased in proportion to the strength of crosswind. The average length of glances to IP, on the other hand, decreased (Figure 13). A significant difference was found between the zero crosswind condition and the higher crosswind conditions in each of these measures.

This difference in the direction of the effect of random crosswind is analogous to the effect of instantaneous workload in the in-car study: the higher workload resulted in an increase in task completion time and average length of glances to the roadway and in a decrease in average length of glances to IP. The strength of random crosswind clearly influenced the driving workload in the simulator. This result also demonstrated that competing VADs existed between IP and the roadway.

There were also significant differences ( $p = 0.0001$ ) among IP task categories in all five dependent measures. As the results of Newman-Keuls tests (Tables 13 through 17) show, the ranking in each measure reflects characteristics of certain task categories. For instance, category Telephone 11 was, by far, the most complex task, in terms of the number of steps, specifically the keypad button actuations, required to complete the task. This characteristic was reflected in the number of glances to IP and (total) hand-off-wheel time. Dialing each digit of a long distance telephone number was not the most difficult task element, as evidenced by the average length of glances to IP (ranked about middle). Overall, the larger number of glances made to IP resulted in the longer task completion time. Similar trend was found in category MGE High.

**Table 12. Newman-Keuls results for effect of Random Crosswind**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Random Crosswind/lb, RMS
A	5.114	120	180
A	4.677	120	120
B	3.866	120	60
B	3.681	120	0

**(b) Dependent Measure: Average length of glances to IP (s)**

Grouping	Mean	n	Random Crosswind/lb, RMS
A	1.117	120	0
B	0.884	120	60
B	0.844	120	180
B	0.789	120	120

**(c) Dependent Measure: Average length of glances to the roadway (s)**

Grouping	Mean	n	Random Crosswind/lb, RMS
A	1.342	120	180
A	1.252	120	120
A B	1.009	120	60
B	0.866	120	0

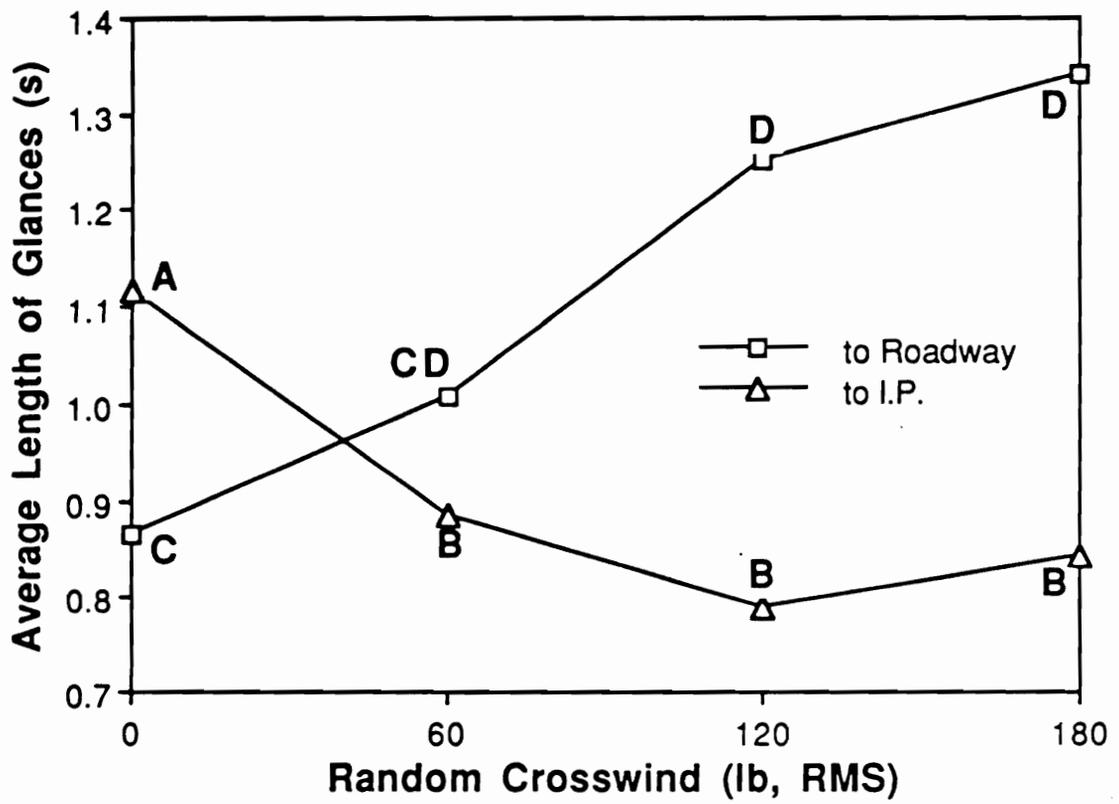


Figure 13. Effect of Random Crosswind (Average lengths of glances)

**Table 13. Newman-Keuls results for IP task category**

Dependent measure: Task completion time (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	10.166	32	Telephone 11
B	5.080	32	MGE High
B	4.819	32	LEDC High
B	4.449	32	Bot 1o12
B	4.394	32	RT 1o9S
B C	4.183	32	PB 1o5
B C	3.890	32	RT 1o4R
B C	3.867	32	MGE Low
B C	3.816	32	Bot 1o3
B C	3.672	32	Top 1o5
B C	3.551	32	Top 1o4
B C	3.540	32	LEDC Step
B C	3.540	32	Bot 1o6
B C	3.446	32	RT 1o4S
C	2.608	32	PB Directed

**Table 14. Newman-Keuls results for IP task category**

Dependent measure: Hand-off-wheel time (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	8.750	32	Telephone 11
B	3.488	32	MGE High
B	3.358	32	LEDC High
C	2.477	32	LEDC Step
C	2.364	32	RT 1o9S
C	2.237	32	MGE Low
C	2.120	32	Bot 1o12
C	1.876	32	PB 1o5
C	1.843	32	RT 1o4R
C	1.760	32	Bot 1o6
C	1.722	32	RT 1o4S
C	1.698	32	Bot 1o3
C	1.694	32	Top 1o5
C	1.691	32	Top 1o4
C	1.477	32	PB Directed

Table 15. Newman-Keuls results for IP task category

Dependent measure: Number of glances to IP  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	5.031	32	Telephone 11
B	2.000	32	LEDC High
C	1.625	32	RT 1o9S
C	1.469	32	MGE High
C D	1.406	32	Bot 1o12
C D	1.250	32	PB 1o5
C D	1.234	32	RT 1o4R
C D	1.219	32	RT 1o4S
D	1.125	32	Bot 1o6
D	1.125	32	LEDC Step
D	1.094	32	Bot 1o3
D	1.094	32	Top 1o5
D	1.094	32	Top 1o4
D	1.078	32	MGE Low
D	1.031	32	PB Directed

**Table 16. Newman-Keuls results for IP task category**

Dependent measure: Average length of glances to IP (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	1.181	32	LEDC High
A B	1.065	32	Bot 1o12
A B C	1.042	32	PB 1o5
A B C	1.036	32	RT 1o9S
A B C D	0.992	32	RT 1o4R
B C D	0.951	32	Top 1o4
B C D E	0.931	32	Bot 1o6
B C D E	0.930	32	Top 1o5
B C D E	0.909	32	Bot 1o3
B C D E	0.868	32	Telephone 11
B C D E F	0.823	32	MGE High
C D E F	0.810	32	RT 1o4S
D E F	0.768	32	MGE Low
E F	0.699	32	PB Directed
F	0.623	32	LEDC Step

**Table 17. Newman-Keuls results for IP task category**

Dependent measure: Average length of glances to the roadway (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	1.611	32	MGE High
A B	1.501	32	LEDC Step
A B C	1.341	32	MGE Low
A B C D	1.276	32	Bot 1o3
B C D	1.126	32	Top 1o4
B C D	1.079	32	Bot 1o12
B C D	1.078	32	PB Directed
B C D	1.074	32	Bot 1o6
B C D	1.060	32	Top 1o5
C D	1.039	32	PB 1o5
C D	0.994	32	RT 1o4R
C D	0.964	32	RT 1o4S
C D	0.943	32	RT 1o9S
D	0.942	32	Telephone 11
D	0.833	32	LEDC High

Category LEDC High was similar to Telephone 11 and MGE High, except that adjustment of LED bar display presented a more difficult task element. This characteristic was reflected in the average length of glances to IP. Category PB Directed, on the other hand, was evidently the easiest task as the target button location was specified in the task instruction, and subjects had thus only to reach and press the button.

Significant interactions between the random crosswind and task category were found in task completion time ( $p = 0.0375$ ) and in the number of glances to IP ( $p = 0.0001$ ). To examine this interaction, analyses of variance were performed for each IP task category, and their results are summarized in Tables 18 and 19. The significant effects of random crosswind for the task categories which were isolated in these analyses are shown in Figures 14 through 18 (Task completion time) and in Figures 19 through 22 (Number of glances to IP). (Crosswind level 1 corresponds to 60 pounds, RMS, level 2 to 120, and level 3 to 180. Error bars indicate the standard deviations.) In general, there was an increasing trend in these dependent measures with the strength of random crosswind.

The analyses of variance for each IP task category also suggest that the significant three-way interaction among gender, task category, and random crosswind was caused by task category PB 1o5. As shown in Figure 23, there was a large difference between gender at the highest crosswind level. A further analysis of data indicated that this interaction in PB 1o5 and the significant effect of gender in MGE High were caused by outliers in the data and not a result of some effect particular to these task categories.

Gender was found to have a significant effect only on the number of glances to IP. This is in agreement with the results of the in-car study. The Newman-Keuls test of the means is provided in Table 20.

The task category means at each level of random crosswind were then compared with the in-car means (age 18 - 25 group at the low and angled auxiliary IP position under the 4-lane limited access

**Table 18. Analyses of variance summary for each IP task category**

Dependent measure: Task completion time  
 Probability values less than 0.05 are shown.

Task Category	Source		
	Gender (G)	Crosswind (C)	G x C
Bot 1o3		0.0335	
Bot 1o6			
Bot 1o12			
LEDC High		0.0035	
LEDC Step		0.0166	
MGE High	0.0229		
MGE Low			
PB Directed		0.0483	
PB 1o5		0.0069	0.0226
RT 1o4R			
RT 1o4S			
RT 1o9S			
Telephone 11			
Top 1o4			
Top 1o5			

**Table 19. Analyses of variance summary for each IP task category**

Dependent measure: Number of glances to IP  
 Probability values less than 0.05 are shown.

Task Category	Source		
	Gender (G)	Crosswind (C)	G x C
Bot 1o3	0.0020		
Bot 1o6			
Bot 1o12			
LEDC High		0.0081	
LEDC Step			
MGE High		0.0314	
MGE Low			
PB Directed			
PB 1o5	0.0117	0.0267	0.0211
RT 1o4R			
RT 1o4S		0.0364	
RT 1o9S			
Telephone 11			
Top 1o4			
Top 1o5			

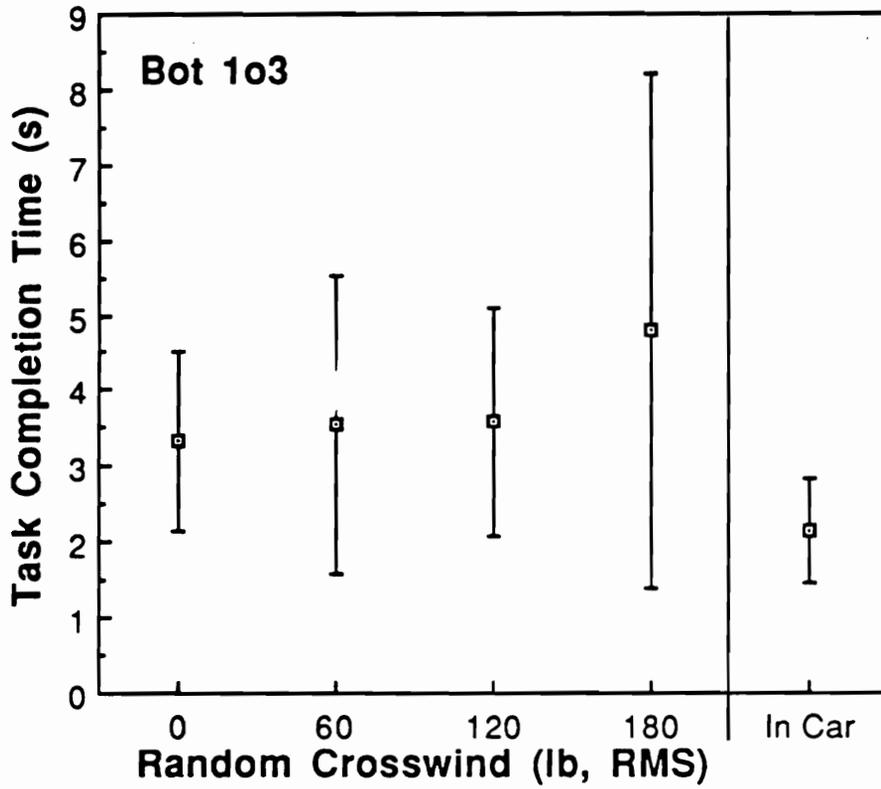


Figure 14. Effect of Crosswind in Bot 103 (Task completion time): Also shown is the in-car study mean

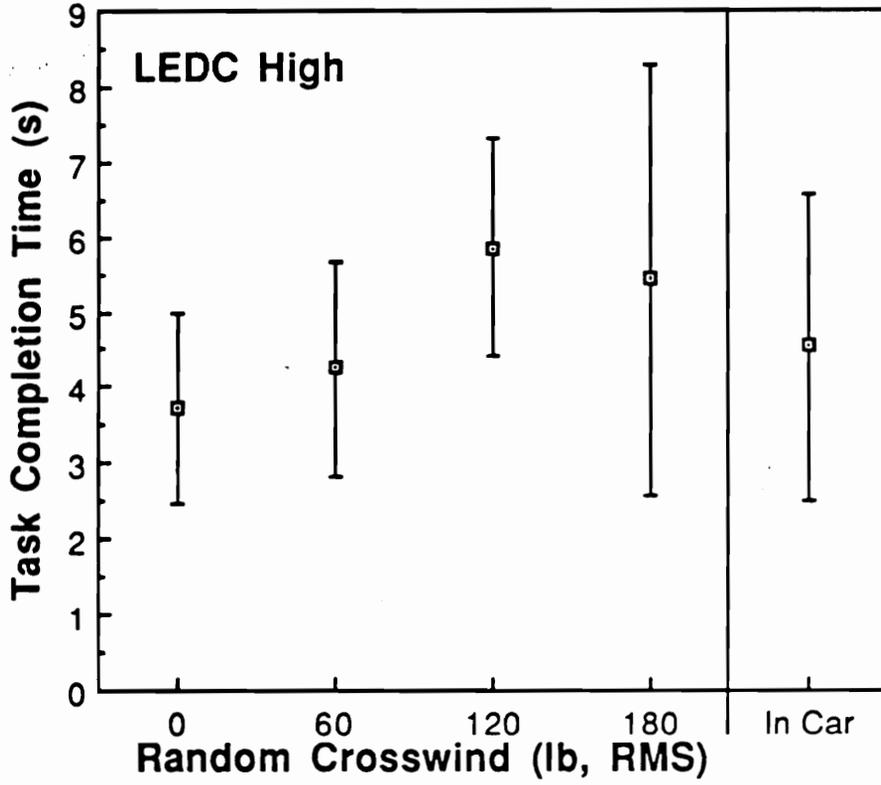


Figure 15. Effect of Crosswind in LEDC High (Task completion time): Also shown is the in-car study mean

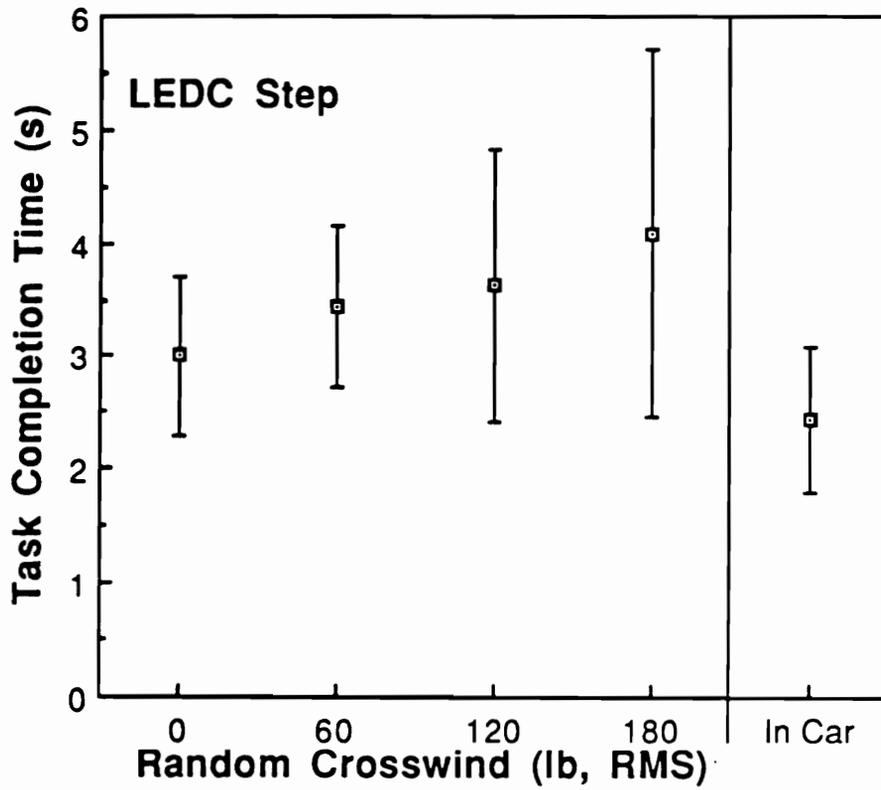


Figure 16. Effect of Crosswind in LEDC Step (Task completion time): Also shown is the in-car study mean

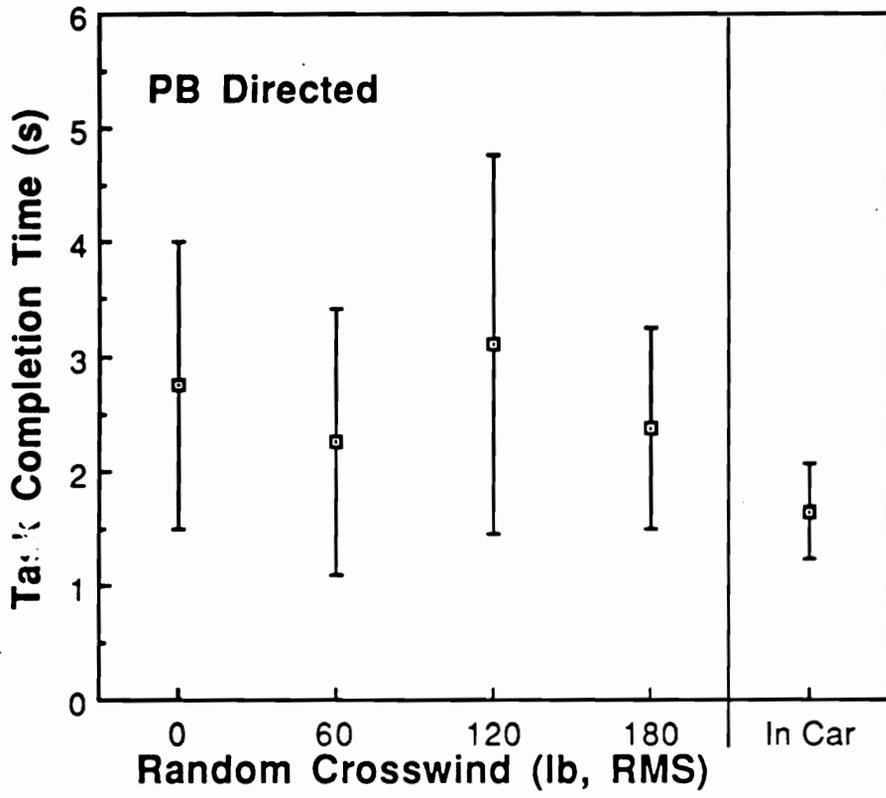


Figure 17. Effect of Crosswind in PB Directed (Task completion time): Also shown is the in-car study mean

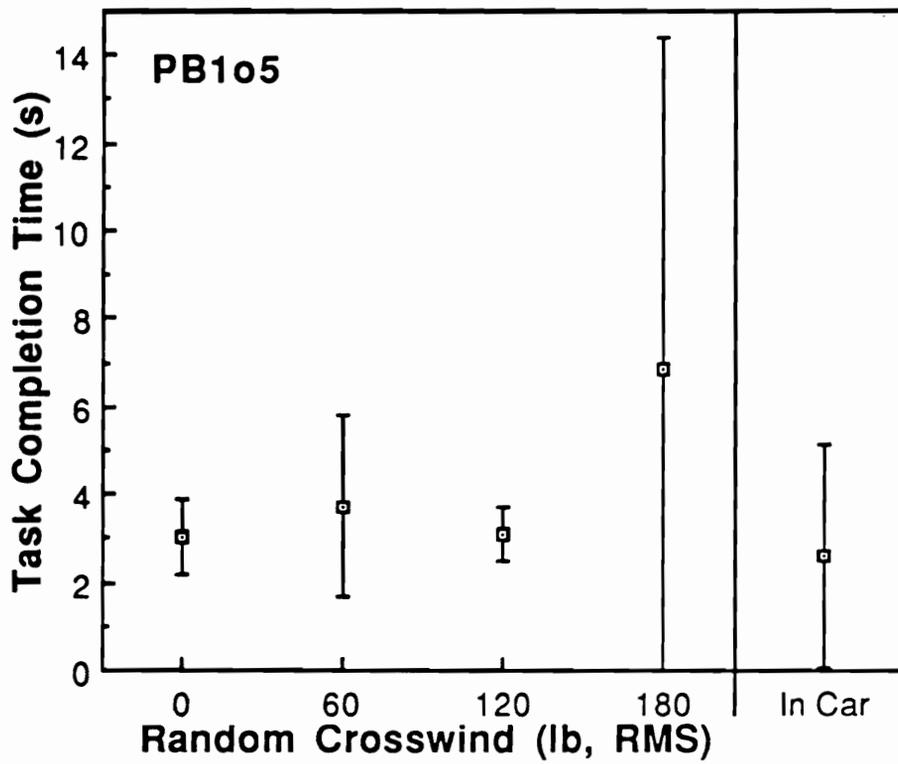


Figure 18. Effect of Crosswind in PB 1o5 (Task completion time): Also shown is the in-car study mean

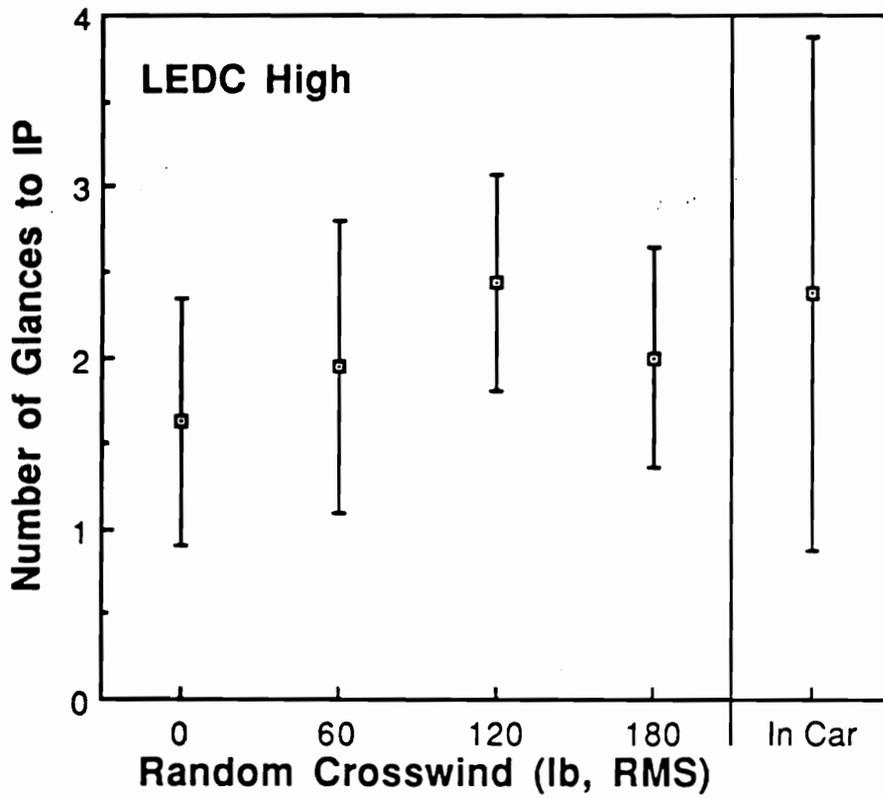


Figure 19. Effect of Crosswind in LEDC High (Number of glances to IP): Also shown is the in-car study mean

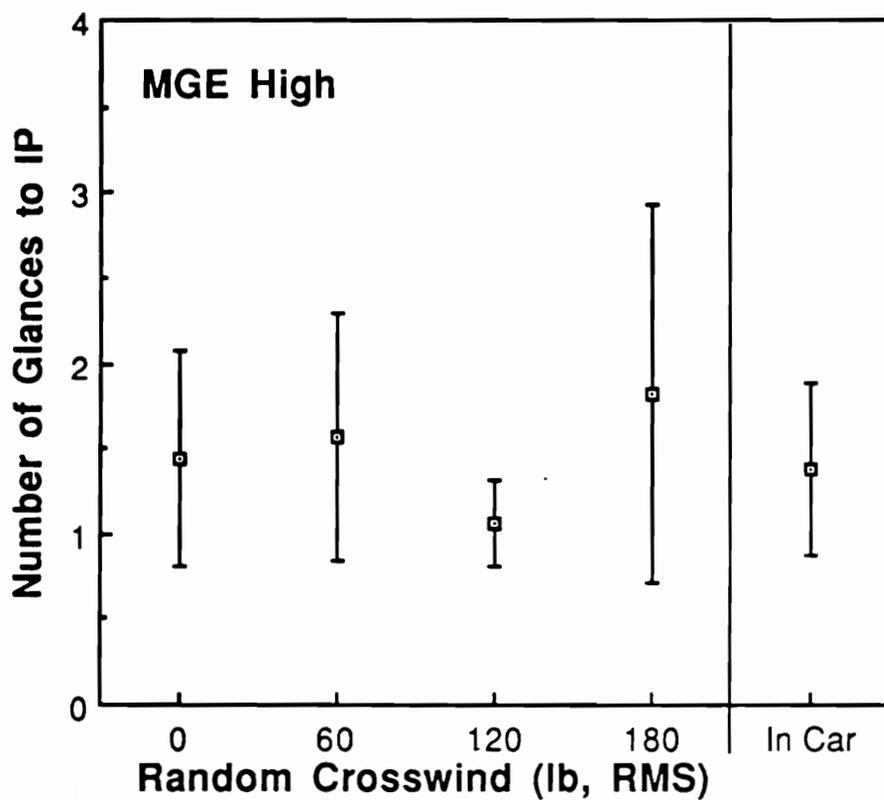


Figure 20. Effect of Crosswind in MGE High (Number of glances to IP): Also shown is the in-car study mean

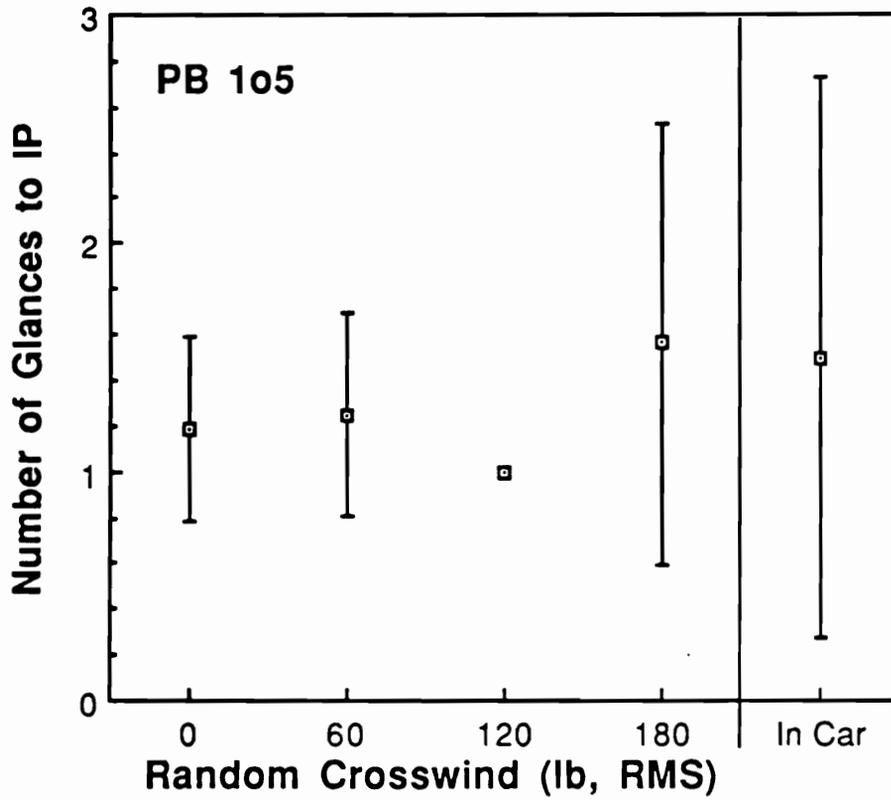


Figure 21. Effect of Crosswind in PB 105 (Number of glances to IP): Also shown is the in-car study mean

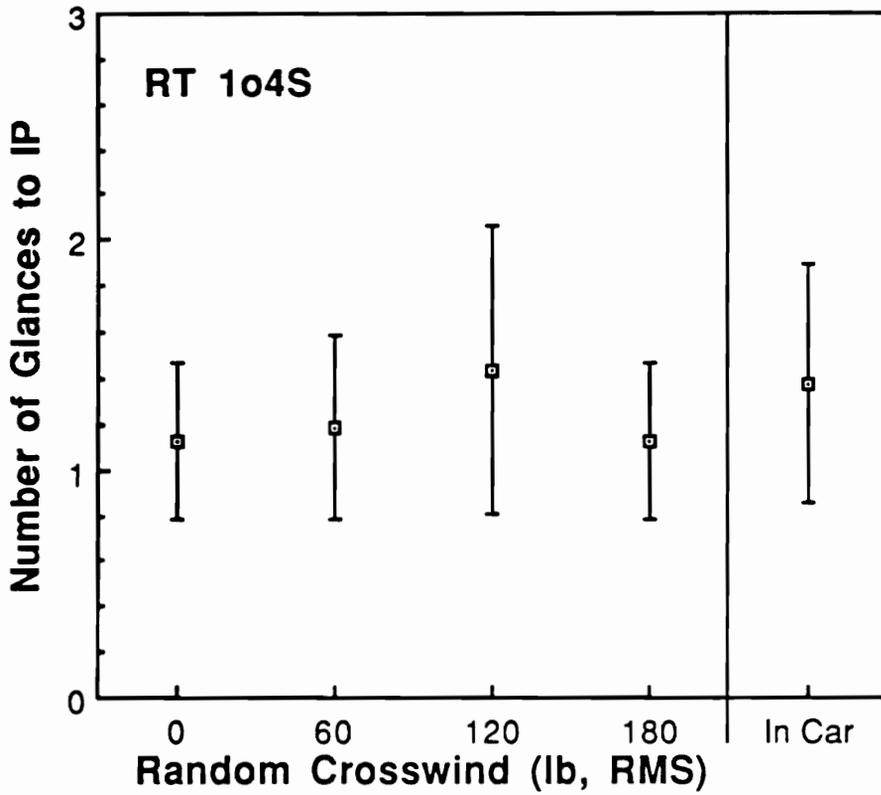


Figure 22. Effect of Crosswind in RT 1o4S (Number of glances to IP): Also shown is the in-car study mean

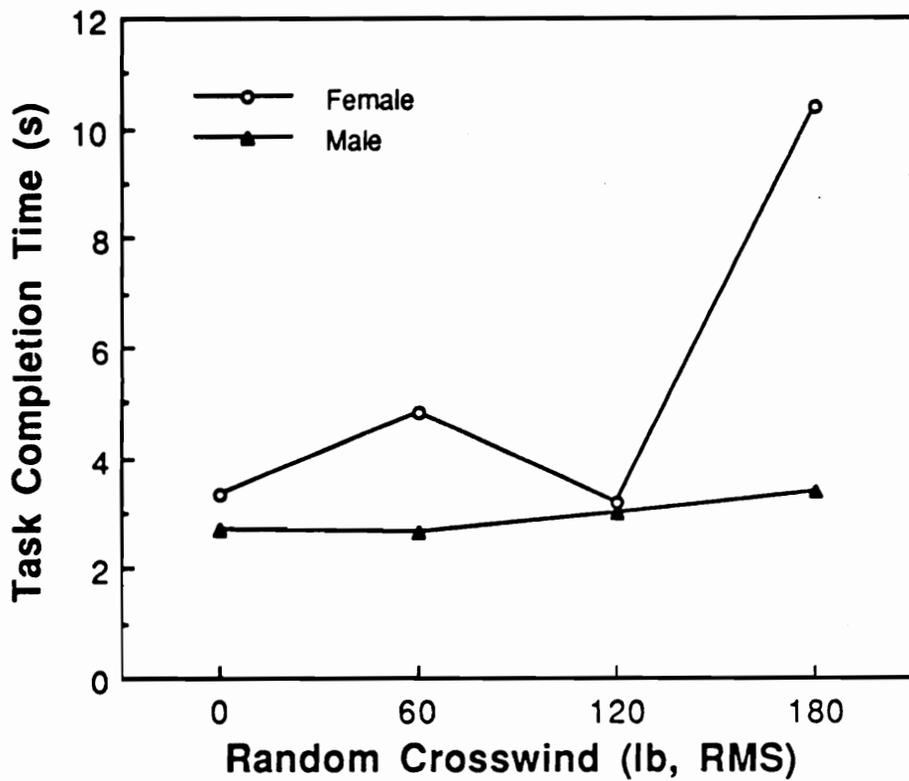


Figure 23. Interaction between Gender and Crosswind in PB 1o5: Task completion time

**Table 20. Newman-Keuls results for Gender (Number of glances to IP)**

Means with the same letter are not significantly different.

Grouping	Mean	n	Gender
A	1.635	240	Female
B	1.415	240	Male

highway driving condition) using pair-wise t-tests. In the number (Figure 27) and average length (Figure 28) of glances to IP (Table 26), the best match between the in-car and in-simulator means was found at the zero crosswind condition. In these measures, a significant ( $p < 0.01$ ) difference in these means was found in only one of 17 task categories. In hand-off-wheel time, there were significant differences in 2 task categories at the zero crosswind condition (Figure 25, Table 22).

The average length of glances to the roadway, on the other hand, was shorter in the car than in the driving simulator (Figure 29). Evidently, the driving simulator exerted a greater visual attentional demand on drivers than the real driving environment did. Possible causes for this difference are that (1) visual cues in the driving simulator are restricted to the forward view (which is presented in a dusk lighting condition and lacks roadside objects and textures), (2) the motion base cues are attenuated, and (3) some delay exists between visual and motion cues.

Long glances made to the roadway in the driving simulator are reflected in the longer task completion time (Figure 24, Table 21). At the zero crosswind condition, significant differences were found in 7 of 17 task categories (in all cases, the in-simulator means were longer); at the 60 pound, RMS, crosswind condition, the means were different in 3 of 17 task categories, however. This finding does not mean that the higher crosswind condition better matched the in-car means. Rather, the inter-subject variances, which are used to compute t-values, were also greater under the higher crosswind condition, thus resulting in fewer significant differences despite the higher task completion means.

**Static simulator runs** The task category means from the static simulator runs were similarly compared with the in-car means. (Only task completion and hand-off-wheel times were measured in the static runs. While performing a task, drivers presumably made one continuous glance to IP.) In task completion time (Figure 24, Table 21), significant differences between the in-car and the static simulator means were found in 5 of 37 task categories. It should be noted that in many of these task categories, significant differences were also found in the dynamic simulator means. This

consistent trend suggests that the manner in which drivers performed these tasks may have changed from the in-car to the in-simulator means, despite the identical task instruction.

In hand-off-wheel time, there were only two significant differences between the in-car and the static simulator means (Figure 25, Table 22). The (total) CMD of each IP task remained constant.

Task category means shown in Figures 24 through 29 and Tables 21 through 23 are combined across the three experiments in this study. Since different sets of task categories were included in each experiment, the number of observations, thus the degrees of freedom, are not constant across task categories. In Figure 23, assuming that one continuous glance was made to IP, the total glance to IP was derived from the mean task completion time by subtracting 0.267 seconds, which was equal to the average length of two eye transitions.

### *Discussions (Experiment 1)*

The main purpose of this study was to “calibrate” the simulator driving workload to the workload associated with in-car driving. The random crosswind was introduced (although it was only one of numerous factors affecting driving conditions) so that the condition under which the relevant dependent measures best matched the real driving environment could be determined.

Comparisons of the IP glance and hand-off-wheel time data indicate that the in-car VAD and CMD of IP tasks are acceptably simulated under the zero crosswind condition in the driving simulator and that the in-simulator values can be used directly to estimate the in-car values. The nature of an IP task, represented by the difficulty of task elements, task complexity, and CMD, was not altered in the driving simulator from the actual driving environment. Furthermore, an in-car task completion time might be estimated from the in-simulator values by adjusting for shorter glances made to the roadway.

Table 21. t-test results for Task completion time

Task Category	In-Car Means	Simulator	t (df)	Means @ 60 kb	t (df)	Static Means	t (df)
Bottle3	2.159	3.212	3.479** (55)	3.555	2.035* (15)	3.113	3.820** (31)
Bottle6	2.818	3.200	1.020 (59)	2.937	0.250 (15)	3.143	0.970 (35)
Bottle12	2.832	4.047	4.065** (68)	4.400	4.525** (15)	3.432	2.891** (44)
Rot2o12	4.701	4.649	0.216 (54)	4.251	0.403 (15)	4.379	0.324 (8)
LEDC High	4.537	3.136	2.953** (53)	3.448	3.215** (15)	5.200	1.157 (31)
LEDC Low	3.910					4.791	1.067 (12)
LEDC Step	2.436					3.447	2.387** (29)
LEDD High	3.803					4.293	0.461 (9)
LEDD Low	3.729					4.240	0.834 (17)
LEDD Step	3.288					3.005	0.557 (12)
File High	2.821	4.839	5.174** (62)	4.471	6.492** (15)	3.988	4.342** (38)
File Low	2.577	3.278	2.788** (58)	2.881	1.075 (15)	3.045	2.040* (34)
Mid AMT	7.256	6.905	0.360 (32)			5.963	1.090 (16)
Mid OTV	5.170					6.521	1.338 (8)
Midlo3	3.394	2.544	3.007** (54)	2.249	1.414 (15)	3.371	0.034 (12)
PB Directed	1.647	3.032	0.634 (20)	3.734	1.091 (15)	2.447	4.629** (30)
PB1o3	2.084					2.721	1.830 (13)
PB1o5	2.584					3.015	0.430 (12)
PB1o15	3.333					3.446	0.133 (12)
PB2o3	3.176					3.360	0.291 (15)
PB2o5	3.050					3.340	0.489 (14)
PB3o15	8.603					5.925	1.488 (9)
PulBalance	3.366					5.580	2.626* (10)
RotBalance	4.617					4.380	0.554 (15)
RT1o4R	2.805	3.119	0.773 (54)	3.224	0.590 (15)	2.917	0.385 (22)
RT1o4S	2.191	2.985	2.264* (54)	2.933	1.656 (15)	2.924	2.295* (30)
RT1o9R	3.914	3.676	2.333** (62)	3.616	1.694* (15)	3.806	0.126 (23)
RT1o9S	3.072					3.337	0.965 (35)
Telephone 1	3.123					2.514	0.782 (9)
Telephone 4	6.318					4.836	1.549 (8)
Telephone 7	7.164					5.753	1.269 (9)
Telephone 11	9.099	9.592	0.329 (49)	9.836	0.498 (15)	7.807	1.394 (25)
TopAMT	13.061	11.878	0.896 (34)			10.374	2.261* (26)
TopFFR	3.817					3.236	1.028 (11)
Top1o4	3.348	2.858	1.470 (24)	2.978	1.183 (15)	3.262	0.157 (16)
Top1o5	2.826	3.086	0.647 (54)	3.479	0.963 (15)	2.814	0.040 (31)
Volume	3.532					3.841	0.426 (15)

\* denotes  $p < 0.05$   
 \*\* denotes  $p < 0.01$

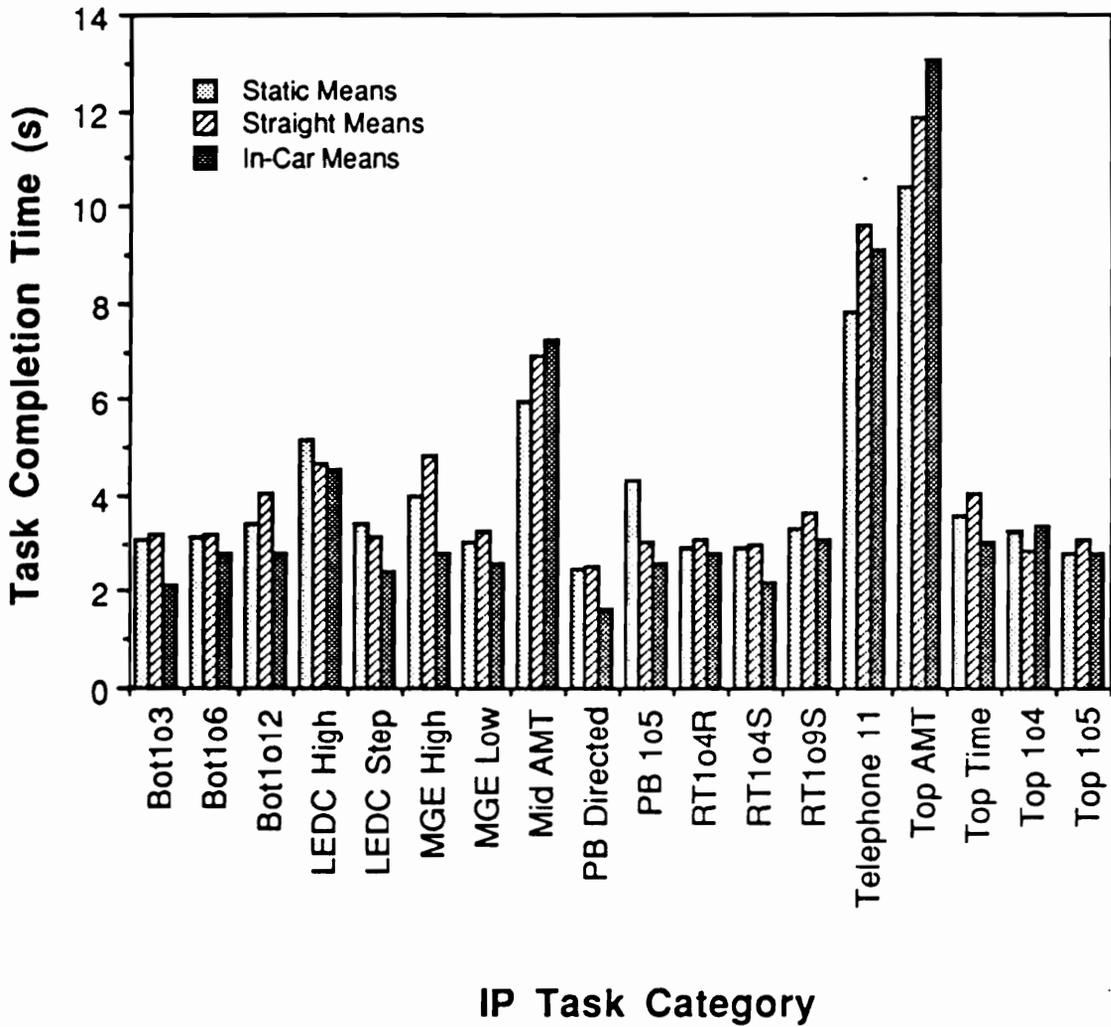


Figure 24. Comparisons of IP task category means (Task completion time)

**Table 22. t-test results for Hand-off-wheel time**

Task Category	In-Car Means	Simulator	t (df)	Static Means	t (df)
Bot1o3	1.414	1.433	0.133 (55)	1.731	1.616 (31)
Bot1o6	1.968	1.609	1.861* (59)	1.857	0.511 (35)
Bot1o12	2.082	1.665	2.619** (68)	2.102	0.090 (44)
Bot2o12	4.018			3.277	0.740 (8)
LEDC High	3.914	3.417	1.032 (54)	4.184	0.499 (31)
LEDC Low	3.604			3.648	0.058 (12)
LEDC Step	2.132	2.271	0.689 (53)	2.441	1.078 (29)
LEDD High	3.276			3.481	0.180 (9)
LEDD Low	3.216			3.053	0.250 (17)
LEDD Step	2.697			2.082	1.773 (12)
MGE High	2.344	3.490	4.184** (62)	3.085	3.320** (38)
MGE Low	2.110	2.060	0.255 (58)	1.984	0.709 (34)
Mid AMT	6.306	5.565	0.807 (32)	4.930	1.577 (16)
Mid OTV	5.044			5.440	0.333 (8)
Mid1o3	2.450			1.728	1.198 (12)
PB Directed	1.180	1.426	1.253 (54)	1.410	1.348 (30)
PB1o3	1.541			1.621	0.283 (13)
PB1o5	1.831	1.729	0.195 (20)	1.696	0.195 (12)
PB1o15	1.831			2.044	0.456 (12)
PB2o3	2.265			2.216	0.113 (15)
PB2o5	2.522			2.340	0.417 (14)
PB3o15	7.028			4.562	1.731 (9)
Pul Balance	2.475			4.176	1.978* (10)
Rot Balance	3.108			3.102	0.011 (15)
RT1o4R	1.780	1.586	1.256 (54)	1.780	0.003 (22)
RT1o4S	1.667	1.737	0.291 (54)	1.686	0.073 (30)
RT1o9R	2.960			2.602	0.489 (23)
RT1o9S	2.549	2.427	0.464 (62)	2.257	1.137 (35)
Tel 1	1.745			1.396	1.322 (9)
Tel 4	4.356			4.194	0.212 (8)
Tel 7	6.586			5.022	1.401 (9)
Telephone 11	8.452	8.531	0.055 (49)	7.024	1.629 (25)
TopAMT	12.723	10.207	2.016* (34)	9.226	2.924** (26)
TopFFP	2.605			2.132	1.186 (11)
Top1o4	2.181	1.634	2.201* (24)	1.991	0.447 (16)
Top1o5	1.496	1.465	0.041 (54)	1.546	0.255 (31)
Volume	2.455			2.762	0.584 (15)

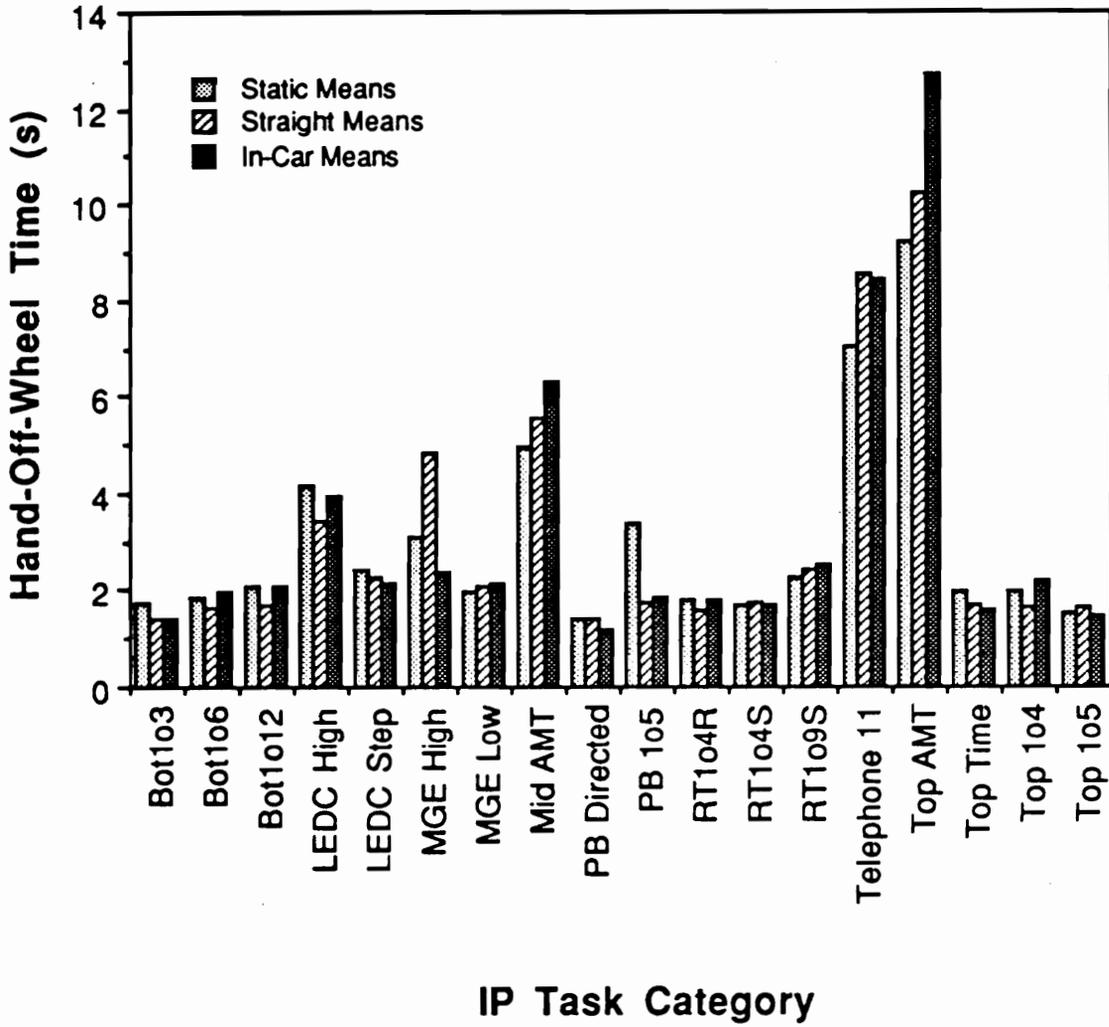


Figure 25. Comparisons of IP task category means (Hand-off-wheel time)

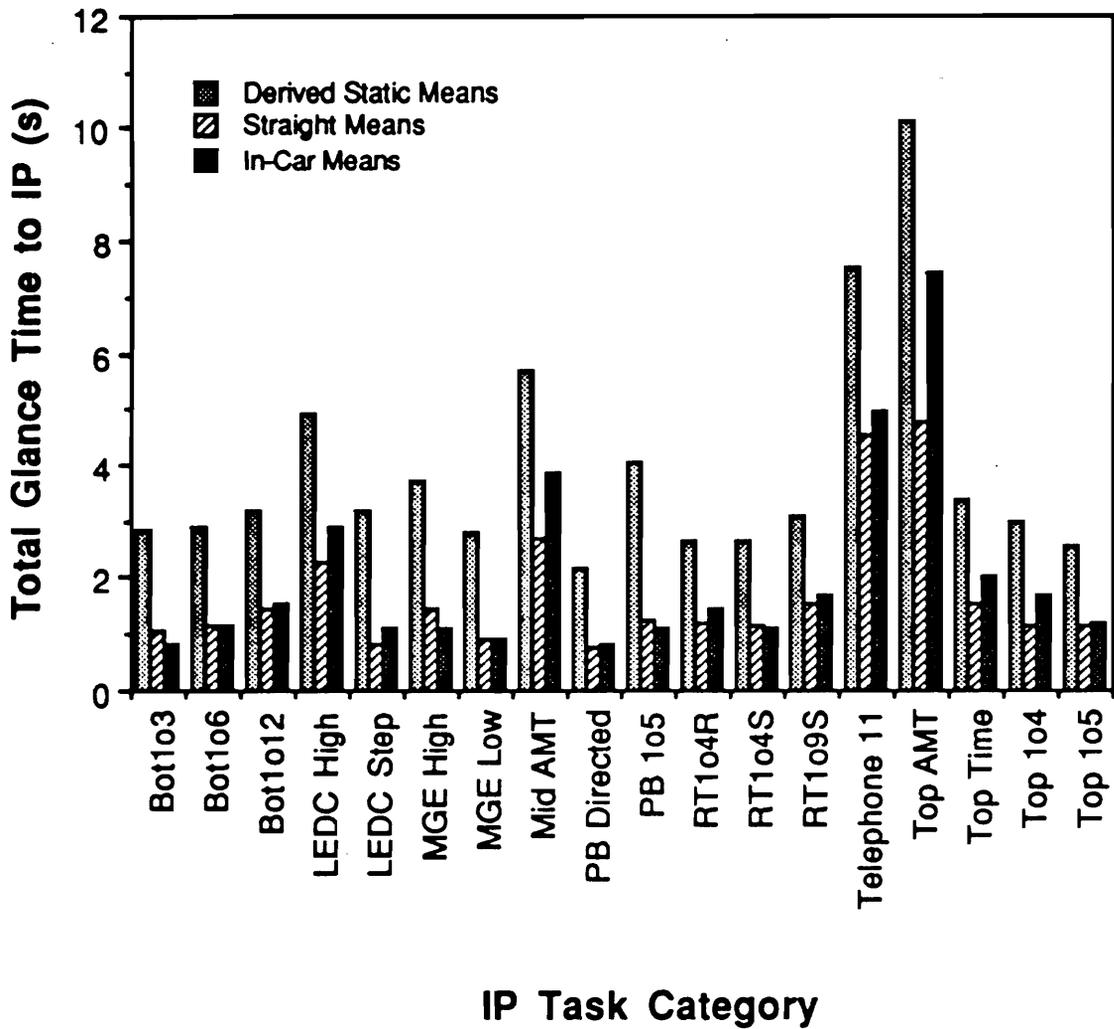


Figure 26. Comparisons of Task category means (Total glance time to IP)

Table 23. t-test results for Glances to IP

Task Category	Number of glances to IP		Average length of glances to IP		df
	In-Car Means	In-Simulator	In-Car Means	In-Simulator	
Bot 1o3	1.000	1.188	0.833	0.892	55
Bot 1o6	1.231	1.302	0.977	0.943	59
Bot 1o12	1.409	1.521	1.177	1.014	68
LEDC High	2.375	2.226	1.495	1.155	54
LEDC Step	1.286	1.229	0.881	0.683	53
MGE High	1.375	1.562	0.856	0.954	62
MGE Low	1.000	1.188	0.908	0.810	58
Mld AMT	4.500	2.953	0.848	0.965	32
PB Directed	1.125	1.042	0.738	0.742	54
PB 1o5	1.500	1.188	0.812	1.114	20
RT 1o4R	1.375	1.260	1.156	0.977	54
RT 1o4S	1.375	1.285	0.877	0.953	54
RT 1o9S	1.562	1.688	1.145	1.036	62
Telephone 11	5.333	5.208	1.143	0.949	49
Top AMT	7.250	5.766	1.089	0.859	34
Top 1o4	1.200	1.125	1.473	1.083	24
Top 1o5	1.250	1.135	1.054	0.924	54

\* denotes p 0.05

\*\* denotes p 0.01

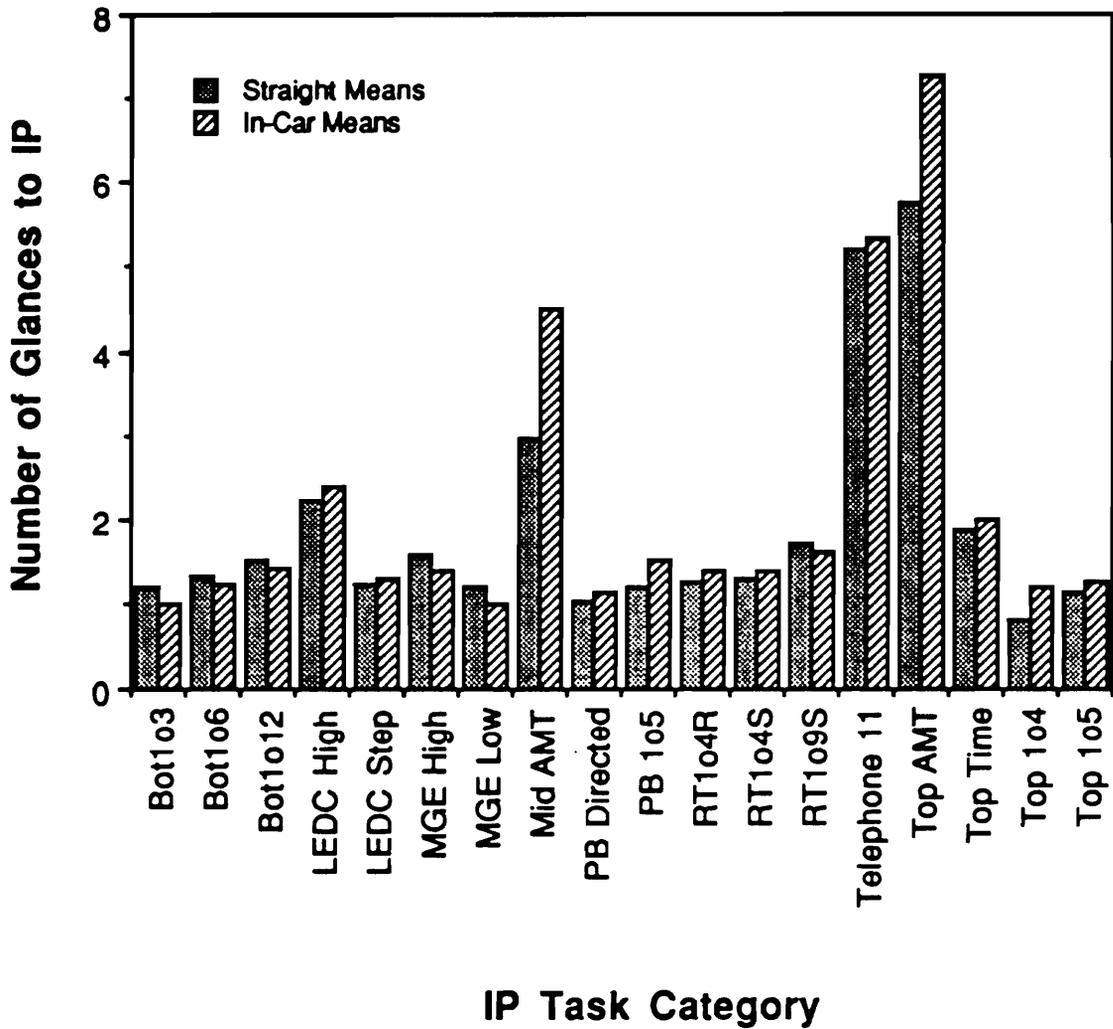


Figure 27. Comparisons of Task category means (Number of glances to IP)

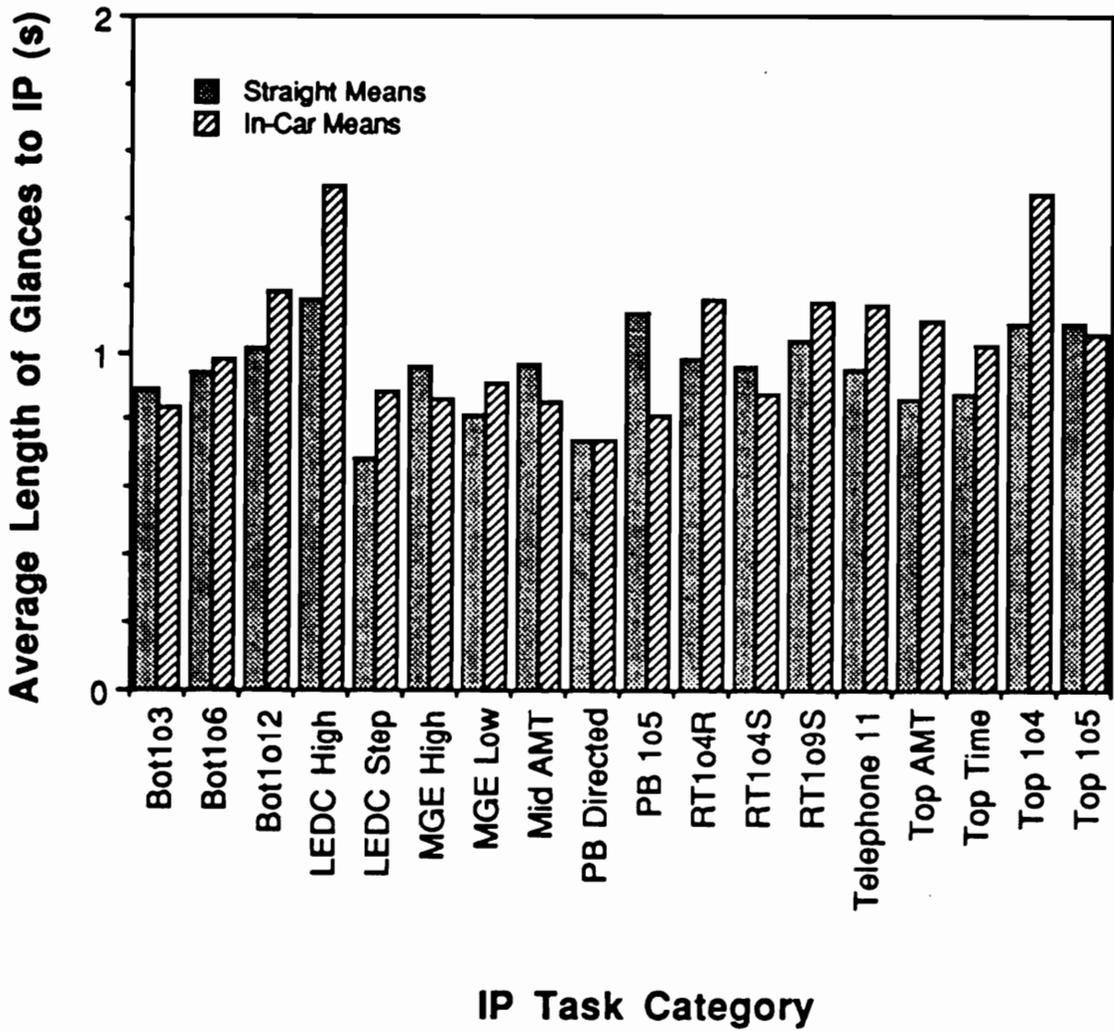


Figure 28. Comparisons of IP task category means (Average glance to IP)

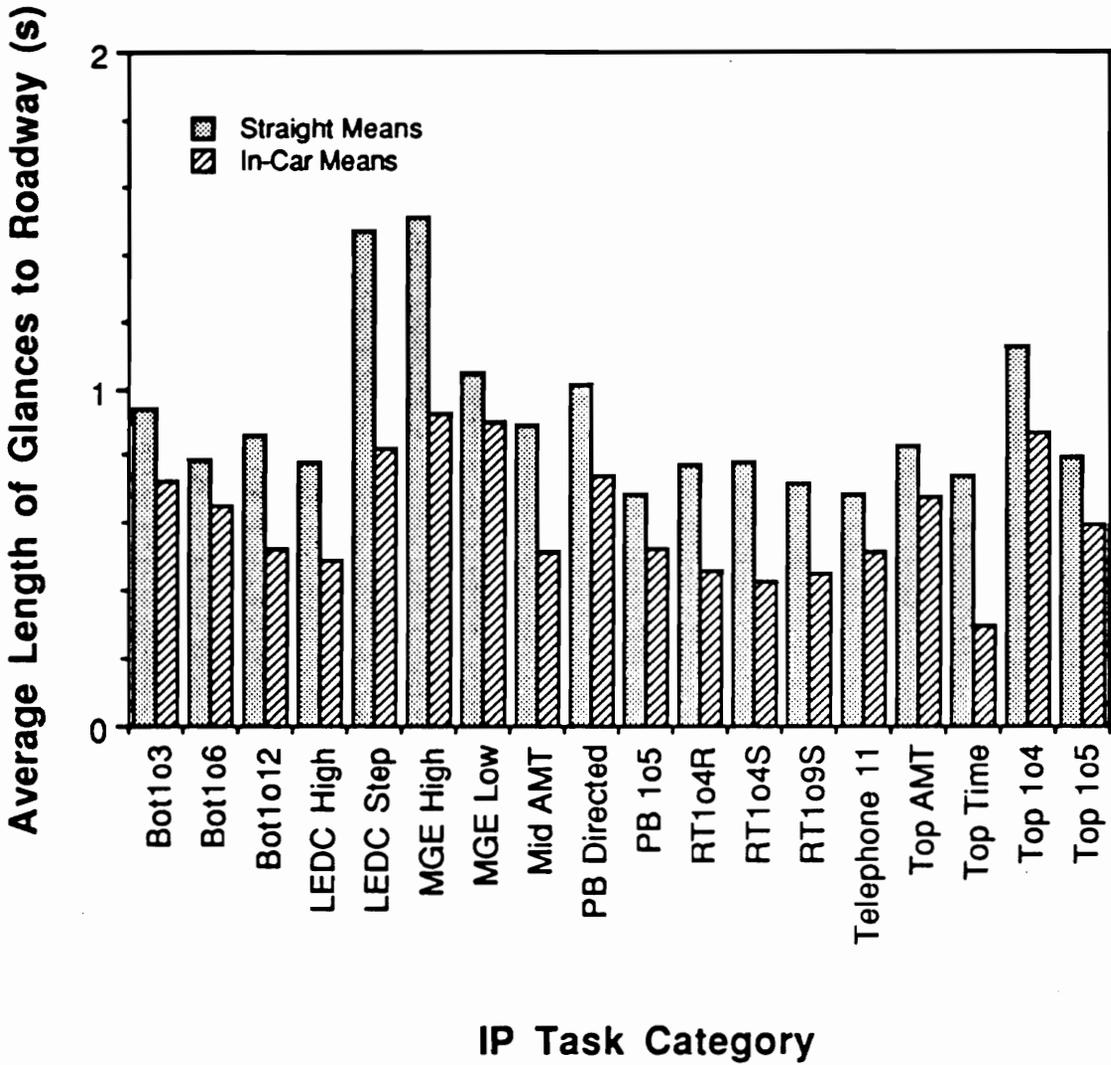


Figure 29. Comparisons of Task category means (Average glance to Roadway)

## Experiment 2: Macroclutter Investigation

### *Macroclutter panels*

Four prototype panels were constructed and mounted above the auxiliary instrument panel and in line with the simulator dashboard (Figure 30). The four types were (1) single cell (Figure 31), (2) triple cells (Figure 32), (3) 2 x 2 cells (Figure 33), and (4) 2 x 3 cells (Figure 34). Each cell was labelled with terms commonly found in automotive instrumentation and contained 6 consecutively numbered "buttons" on the left half, while the right half contained 6 buttons with randomly assigned letters of the alphabet. The level of instrument panel (IP) macroclutter was thus varied by the number of cells contained in each prototype panel. During the experiment session, subjects were instructed to press a specific button in one of the cells.

The issue of IP macroclutter is increasingly important in vehicular cockpit design because of the technological advances in instrumentation. For example, the numbers of displays and controls have dramatically increased, even in the last decade, as the number of functions available in automobile has multiplied. Whether to continue adding new instrumentation to the limited space of vehicle dashboard or to replace with such a multifunctional device as a touch panel display is certainly a pertinent issue in vehicular IP design.

### *Procedure (Experiment 2)*

Eight subjects (4 female and 4 male) with a median age of 21-1/2 years (ranging from 19 to 26 years; median number of years driving: 5-1/2) participated in this experiment. At the beginning of the session, subjects were seated in the driving simulator, and the operations of various controls on the auxiliary IP panel were explained to them. Four static "runs" which followed the introduction were intended to familiarize subjects with the types of IP tasks which they would be instructed to perform, as well as to measure their task performance while not driving (Figure 35). (A detailed description of static runs is given below.)

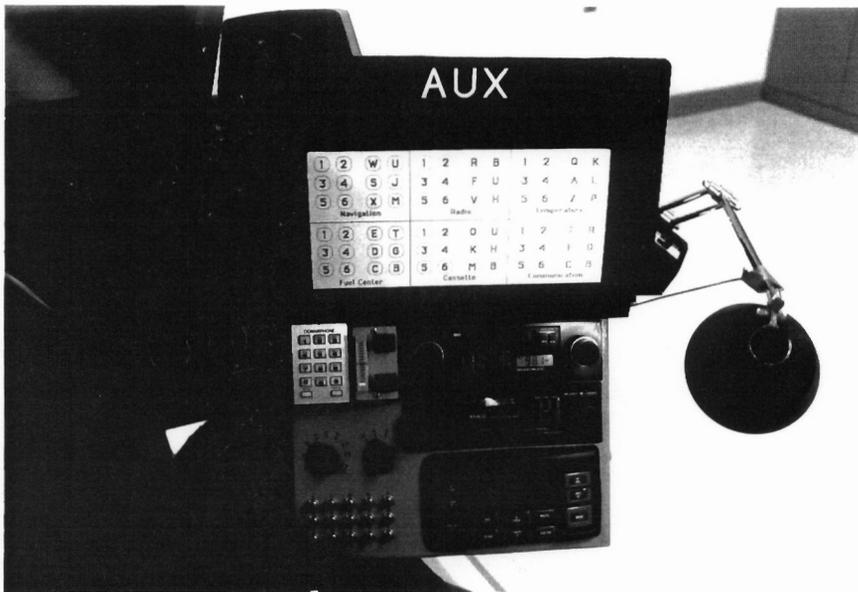


Figure 30. Prototype macroclutter panel with auxiliary IP

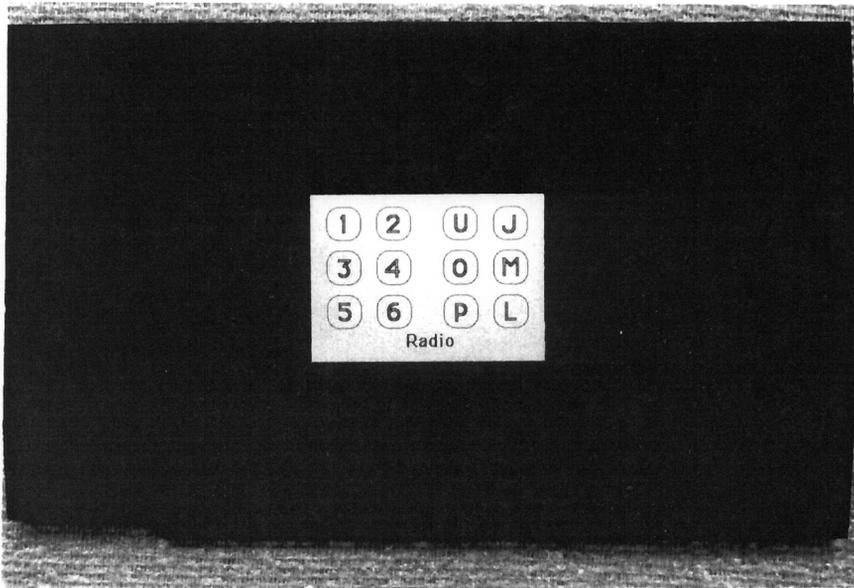


Figure 31. Single cell prototype panel

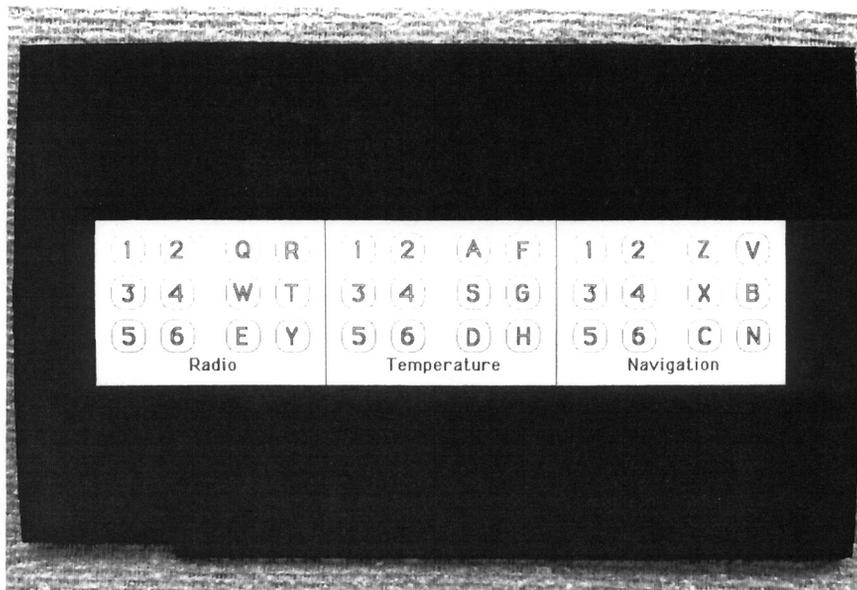


Figure 32. Triple cell prototype panel

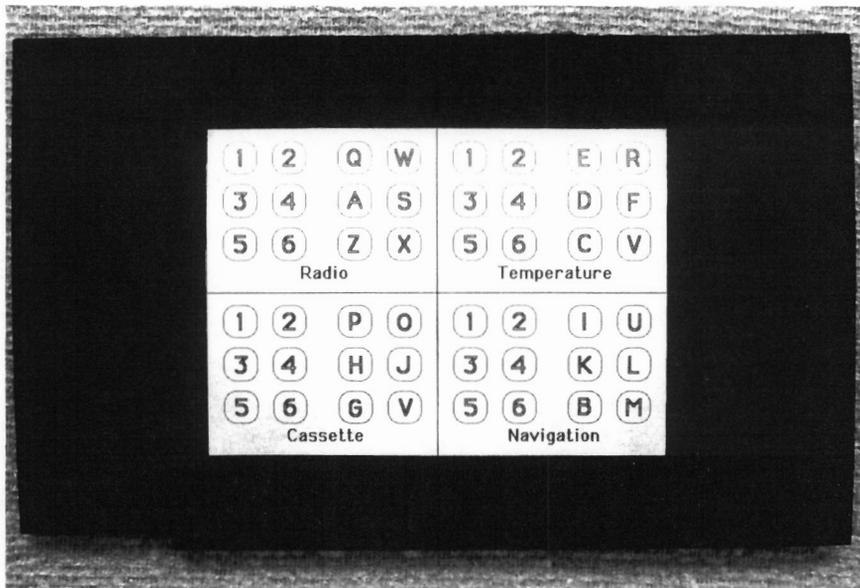


Figure 33. 2 x 2 cell prototype panel

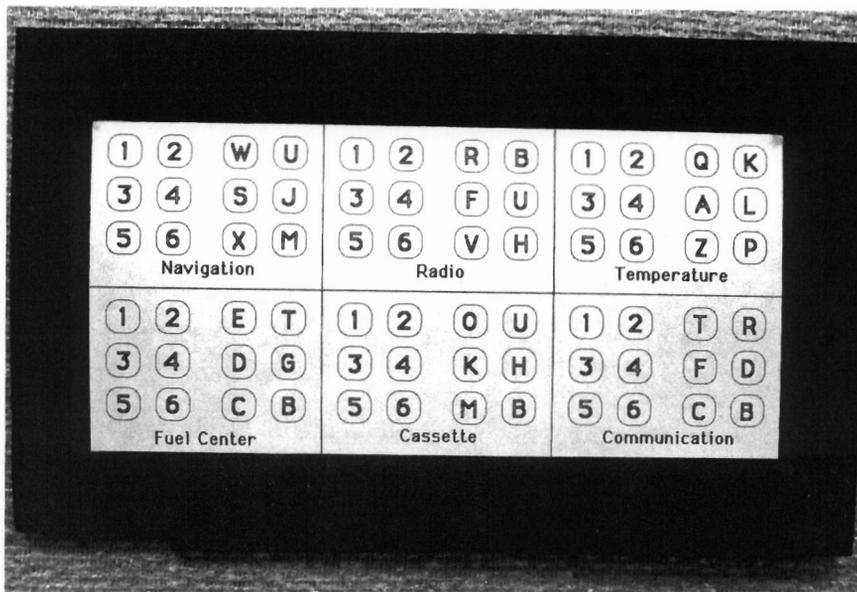


Figure 34. 2 x 3 cell prototype panel

## Experiment 2 Session Timeline

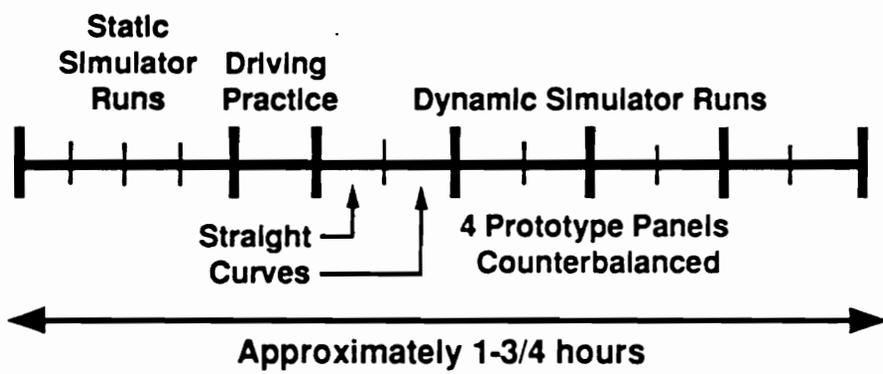


Figure 35. Experiment 2 Session Timeline

Subjects were then shown how to "drive" the simulator and were given several minutes to become familiar with its handling. The driving practice was provided both with and without tasks to perform. A short break followed the practice.

Subject's task performance while driving was measured during four simulator runs (a detailed description of which is provided below). Midway through these runs, another break was offered. At the end of an experimental session, which lasted approximately 2 hours, subjects were debriefed and compensated for their participation.

**Static simulator runs** Sixteen of the forty-one auxiliary IP task categories used in the Hayes et al. (1988) in-car study were selected for use in both static and dynamic simulator runs (Table 24). Of these, thirteen were also used during the dynamic simulator runs in Experiment 1. Two task categories which required manual tuning of radios and a task category which required reading time were included in this experiment.

For each static run, a different macroclutter panel was mounted and one observation of each task category, including those using the macroclutter panel, was made, and the ordering of tasks was made in a randomized order (Appendix E). Subjects were instructed to keep their hands on the steering wheel and their eyes on the roadway as if they were stopped at a traffic light. Their task completion times and hand-off-wheel times were measured. (Their eye movements were also recorded on a VCR.)

**Dynamic simulator runs** Each of the four dynamic simulator runs consisted of two portions differing in the type of simulated roadway. A dynamic simulator run began with a straight 2-lane roadway, followed by a portion including various sized curves (both with no other vehicle in the scene). During the straight roadway portion, a lane deviation tone was provided to insure that subjects did not neglect driving and concentrate on performing IP tasks, a lane deviation tone (called a "lane minder") was provided. The tone sounded whenever the simulated vehicle strayed from the assigned (right) lane of roadway.

**Table 24. List of IP task categories (Experiment 2)**

<b>Task Category</b>	<b>Description</b>
Bot 1o3*	Bottom (Pontiac) radio. Press one of three buttons.
Bot 1o6*	Bottom (Pontiac) radio. Press one of six buttons.
Bot 1o12*	Bottom (Pontiac) radio. Press one of twelve buttons.
LEDC High*	LED Continuous mode. High accuracy adjustment.
LEDC Step*	LED Continuous mode. Step-wise adjustment.
MGE High*	Middle (Kraco) radio graphic equalizer. High accuracy adjustment.
MGE Low*	Middle (Kraco) radio graphic equalizer. Low accuracy adjustment.
Mid AMT	Middle (Kraco) radio. Press FM/AM then tune.
PB Directed*	Pushbutton array. Button location directed.
RT 1o4R*	4-position rotary knob. Alphabet selection.
RT 1o4S*	4-position rotary knob. Numeral selection.
RT 1o9S*	9-position rotary knob. Numeral selection.
Telephone 11*	Telephone keypad. Dial 13 digits.
Top AMT	Top (Sparkomatic) radio. Press AM/FM then tune.
Top Time	Top (Sparkomatic) radio. Read present time.
Top 1o5*	Top (Sparkomatic) radio. Press one of five buttons.

\* denotes task categories included in Experiment 1

Each portion of a dynamic simulator run included two observations of the 16 auxiliary IP task categories using the macroclutter panels, and non-measured tasks, such as asking subjects to read the present vehicle speed and to read a word on a slide.

The videotape which recorded subjects' eye movements while performing tasks was analyzed after the experimental session, and the number and length of glances to roadway, to IP, to other points, and in transition were determined. Statistical analyses of these measures, as well as the task completion and hand-off-wheel times, were then performed using the Statistical Analysis System on the University's IBM 3090 computer.

Task ordering was completely randomized for each portion of the dynamic simulator runs (Appendix E). In order to clarify the experimental design, the auxiliary IP tasks and macroclutter panel tasks are described separately below.

**Auxiliary IP tasks** A  $2 \times 16 \times 4$  full factorial within-subject design using 8 subjects and 2 repeated measures per cell was used for this portion of the dynamic simulator runs, using the auxiliary IP. The independent variables were the type of roadway, task category and presentation order.

**Macroclutter panel tasks** A  $2 \times 4 \times 2$  full factorial within-subject design with repeated measures using 8 subjects was used for this portion of the dynamic simulator runs. The independent variables were the type of roadway, macroclutter panels, and type of button labeling (letters of the alphabet and numerals).

One set of task instructions was provided with one of the four macroclutter panels. This matching of task instruction and macroclutter panel configuration was not considered to cause any bias, as task ordering was completely randomized. The presentation order of macroclutter panels was counterbalanced in such a way that should the presentation order have a significant effect on dependent measures, the data could then be reanalyzed as a  $2 \times 4 \times 2 \times 4 \times 2$  Latin square design.

That is, a Latin square was repeated for each gender, while all combinations of the original three independent variables (roadway, panel, and label) were maintained in the Latin square.

### *Results (Experiment 2)*

**Auxiliary IP tasks** The results of analyses of variance for auxiliary IP tasks are summarized in Table 25. As in Experiment 1, the task category had significant effects on all five of the dependent measures included in these analyses (i.e., task completion time, hand-off-wheel time, number of glances to IP, and average lengths of glances to roadway and to IP). The results of Newman-Keuls tests are shown in Tables 26 through 30.

The type of simulated roadway had significant effects on task completion time and average length of glances to roadway and to IP. The Newman-Keuls tests (Table 31) show that longer times resulted under the route with curves in the first two measures; the order was reversed for the average length of glances to IP, however. This is analogous to the effect of random crosswind in Experiment 1. Driving through curves obviously required subjects to pay greater attention to maintaining a proper vehicle position, and the task completion time and average length of glances to roadway were thus longer, while subjects took shorter glances to IP.

The presentation order was included in the experiment design to allow the factors that might influence task performance over time, e.g., practice/learning and fatigue, to be examined. (Presentation Order number 1 corresponds to the first dynamic simulator run, number 2 to the second, and so on.) Testing for this factor, which was possible because of the full factorial design, showed significant effects on task completion time, hand-off-wheel time, and average length of glances to roadway. The results of Newman-Keuls tests are shown in Table 32. (There were no significant differences among the means for length of glances to roadway.) Clearly, practice/learning had a significant effect on these measures.

Table 25. Analyses of variance summary (Experiment 2 IP tasks)

Probability values less than 0.05 are shown.

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Gender (G)	1					
Road (R)	1	0.0053		0.0039		0.0033
Task Category (T)	15	0.0001	0.0001	0.0001	0.0001	0.0001
Presentation Order (O)	3	0.0019	0.0022	0.0236		
R x T	15	0.0012	0.0001		0.0001	
R x O	3					
T x O	45	0.0005	0.0001	0.0006	0.0001	
G x R	1					
G x T	15			0.0408		
G x O	3					
R x T x O	45					0.0346
G x T x O	45					
G x R x O	3					
G x R x T	15					
G x R x T x O	45					

**Table 26. Newman-Keuls results for IP task category**

Dependent measure: Task completion time (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	11.634	64	Top AMT
B	10.550	64	Telephone 11
C	7.433	64	Mid AMT
D	5.505	64	MGE High
D E	5.117	64	LEDC High
E F	4.462	64	Bot 1o12
F G	4.230	64	Top Time
F G H	3.846	64	RT 1o9S
F G H	3.683	64	MGE Low
F G H	3.674	64	Bot 1o6
F G H	3.579	64	LEDC Step
F G H I	3.494	64	Bot 1o3
G H I	3.401	64	Top 1o5
G H I	3.226	64	RT 1o4R
H I	3.013	64	RT 1o4S
I	2.595	64	PB Directed

**Table 27. Newman-Keuls results for IP task category**

Dependent measure: Hand-off-wheel time (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	9.559	64	Top AMT
A	9.159	64	Telephone 11
B	5.885	64	Mid AMT
C	3.856	64	MGE High
C	3.486	64	LEDC High
D	2.438	64	LEDC Step
D E	2.216	64	RT 1o9S
D E	2.040	64	MGE Low
D E	1.777	64	Top Time
E	1.655	64	RT 1o4R
E	1.581	64	RT 1o4S
E	1.541	64	Bot 1o6
E	1.491	64	Bot 1o12
E	1.487	64	Bot 1o3
E	1.468	64	Top 1o5
E	1.330	64	PB Directed

**Table 28. Newman-Keuls results for IP task category**

Dependent measure: Average length of glances to the roadway (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	1.675	64	LEDC Step
B	1.489	64	MGE High
C	1.250	64	MGE Low
D	1.024	64	PB Directed
D	1.019	64	Bot 1o3
D	0.958	64	Top AMT
D	0.954	64	Mid AMT
D	0.946	64	Top 1o5
D	0.936	64	Bot 1o6
D	0.936	64	Bot 1o12
D	0.892	64	RT 1o4S
D	0.844	64	RT 1o9S
D	0.844	64	LEDC High
D	0.818	64	Top Time
D	0.818	64	RT 1o4R
D	0.801	64	Telephone 11

**Table 29. Newman-Keuls results for IP task category**

Dependent measure: Number of glances to IP  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	5.617	64	Telephone 11
A	5.336	64	Top AMT
B	3.117	64	Mid AMT
C	2.380	64	LEDC High
D	1.891	64	Top Time
D E	1.784	64	MGE High
D E	1.766	64	Bot 1o12
D E F	1.680	64	RT 1o9S
D E F	1.423	64	Bot 1o6
D E F	1.383	64	RT 1o4R
E F	1.289	64	RT 1o4S
E F	1.266	64	Bot 1o3
E F	1.227	64	LEDC Step
E F	1.203	64	Top 1o5
E F	1.148	64	MGE Low
F	1.068	64	PB Directed

**Table 30. Newman-Keuls results for IP task category**

Dependent measure: Average length of glances to IP (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	0.945	64	LEDC High
A B	0.919	64	Mid AMT
A B	0.901	64	MGE High
A B C	0.879	64	Bot 1o12
A B C	0.863	64	Top 1o5
A B C	0.853	64	RT 1o9S
A B C	0.847	64	Bot 1o6
A B C	0.843	64	RT 1o4R
A B C	0.840	64	Telephone 11
A B C	0.836	64	Top Time
A B C	0.815	64	Top AMT
A B C	0.791	64	RT 1o4S
B C D	0.757	64	Bot 1o3
C D	0.716	64	MGE Low
D E	0.655	64	PB Directed
E	0.575	64	LEDC Step

**Table 31. Newman-Keuls results for Simulated Roadway**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Roadway Type
A	5.231	512	Curves
B	4.699	512	Straight

**(b) Dependent Measure: Average Length of Glances to Roadway (s)**

Grouping	Mean	n	Roadway Type
A	1.097	512	Curves
B	0.929	512	Straight

**(c) Dependent Measure: Average Length of Glances to IP (s)**

Grouping	Mean	n	Roadway Type
A	0.842	512	Straight
B	0.788	512	Curves

**Table 32. Newman-Keuls results for Presentation Order**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Presentation Order
A	5.259	256	1
A B	5.029	256	2
B C	4.859	256	3
C	4.713	256	4

**(b) Dependent Measure: Hand-Off-Wheel Time (s)**

Grouping	Mean	n	Presentation Order
A	3.361	256	1
A B	3.219	256	2
B	3.113	256	3
B	3.049	256	4

Analyses of variance for each task category, summarized in Tables 33 through 37, were performed to study the significant interactions involving task category. The type of simulated roadway had significant effects in certain task categories (Tables 33, 34, and 36), resulting in the significant interaction with task category. In task completion time, the longer means were recorded with curves; in hand-off-wheel time, however, the ordering was reversed for four of the nine task categories (i.e., LEDC High, RT 1o4S, RT 1o9S, and Top AMT).

The significant interactions between task category and presentation order were evidently caused by the significant effect of presentation order on a single task category. It is interesting to note that the task completion time and average length of glances to IP in task category Telephone 11 were significantly influenced by presentation order. Furthermore, the Newman-Keuls tests of these means (Table 38) revealed that their grouping was identical to the grouping in the main analyses (across task categories).

In the in-car study and Experiment 1, there was a significant effect of gender on the average length of glances to roadway. In this experiment, however, the effect of gender was found to be significant only in task categories RT 1o4S and Top 1o5, resulting in the marginally significant ( $p = 0.0408$ ) interaction between gender and task category.

The task category means under the straight roadway condition for the 13 categories in common with Experiment 1 were compared with those in the first experiment's zero crosswind condition. Analyses of variance (Table 39) show that there was no significant difference between the two experiments in task completion time, hand-off-wheel time, and average length of glances to the roadway. There were, however, significant differences between the two experiments in number and average length of glances to IP. This difference is attributed to the instructions to subjects. In this experiment, in order to keep subjects from neglecting driving as their primary task and diverting their attention completely to performing IP tasks, they were advised to "sample", or allocate their attention, between driving and IP. It was intended to make the simulator driving as close as pos-

**Table 33. Analysis of variance summary for each IP task category**

Dependent measure: Task completion time  
 Probability values less than 0.05 are shown.

Task Category	Source				
	Gender (G)	Road (R)	G x R	Presentation Order (O/R)	G x O/R
Bot 1o3		0.0033			
Bot 1o6					
Bot 1o12		0.0187			
LEDC High					
LEDC Step		0.0010			
MGE High		0.0094			
MGE Low		0.0054	0.0248		0.0459
Mid AMT		0.0025			
PB Directed		0.0466			
RT 1o4R					
RT 1o4S					
RT 1o9S					
Telephone 11				0.0019	
Top AMT					
Top Time					
Top 1o5		0.0151			

**Table 34. Analysis of variance summary for each IP task category**

Dependent measure: Hand-off-wheel time  
 Probability values less than 0.05 are shown.

Task Category	Source				
	Gender (G)	Road (R)	G x R	Presentation Order (O/R)	G x O/R
Bot 1o3		0.0077			
Bot 1o6				0.0491	
Bot 1o12					0.0249
LEDC High		0.0326	0.0298		
LEDC Step		0.0010			
MGE High		0.0185	0.0223		
MGE Low			0.0106		
Mid AMT		0.0253			
PB Directed					
RT 1o4R		0.0422			
RT 1o4S		0.0330			
RT 1o9S		0.0127			
Telephone 11				0.0050	
Top AMT		0.0350			
Top Time					
Top 1o5					

**Table 35. Analysis of variance summary for each IP task category**

Dependent measure: Average length of glances to the roadway  
 Probability values less than 0.05 are shown.

Task Category	Source				
	Gender (G)	Road (R)	G x R	Presentation Order (O/R)	G x O/R
Bot 1o3					0.0301
Bot 1o6					
Bot 1o12					
LEDC High		0.0339			
LEDC Step		0.0454		0.0036	
MGE High			0.0448		
MGE Low		0.0422			
Mid AMT		0.0080			
PB Directed		0.0058			
RT 1o4R					
RT 1o4S	0.0310	0.0111			
RT 1o9S		0.0431			
Telephone 11					
Top AMT		0.0104			
Top Time		0.0207			
Top 1o5	0.0469				

**Table 36. Analysis of variance summary for each IP task category**

Dependent measure: Number of glances to IP  
 Probability values less than 0.05 are shown.

Task Category	Source				
	Gender (G)	Road (R)	G x R	Presentation Order (O/R)	G x O/R
Bot 1o3					
Bot 1o6					
Bot 1o12		0.0274			
LEDC High					
LEDC Step					
MGE High		0.0383			
MGE Low					
Mid AMT					
PB Directed					
RT 1o4R					
RT 1o4S					
RT 1o9S					
Telephone 11				0.0009	
Top AMT		0.0104			
Top Time					
Top 1o5		0.0447			

**Table 37. Analysis of variance summary for each IP task category**

Dependent measure: Average length of glances to IP  
 Probability values less than 0.05 are shown.

Task Category	Source				
	Gender (G)	Road (R)	G x R	Presentation Order (O/R)	G x O/R
Bot 1o3					
Bot 1o6				0.0467	
Bot 1o12		0.0187			
LEDC High					
LEDC Step					
MGE High					
MGE Low					
Mid AMT					
PB Directed		0.0489	0.0396		
RT 1o4R					
RT 1o4S		0.0367			
RT 1o9S					
Telephone 11					
Top AMT		0.0222			
Top Time					
Top 1o5					

**Table 38. Newman-Keuls results for Presentation Order in Telephone 11**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Presentation Order
A	11.744	16	1
A B	10.935	16	2
B C	10.089	16	3
C	9.439	16	4

**(b) Dependent Measure: Hand-Off-Wheel Time (s)**

Grouping	Mean	n	Presentation Order
A	10.230	16	1
A B	9.331	16	2
B	8.924	16	3
B	8.150	16	4

sible to the actual driving environment, and the instruction evidently had a significant effect in altering these measures.

**Macroclutter panel tasks** The results of analyses of variance for macroclutter panel tasks are summarized in Table 40. As in the auxiliary IP tasks, the type of simulated roadway had a significant effect on task completion time and average length of glances to roadway and to IP. The Newman-Keuls tests (Table 41) show, once again, that longer times resulted while driving through curves in the first two measures and in shorter glances made to the macroclutter panel.

The macroclutter panels were found to have a significant effect on task completion time and on the number of glances to the panels. The Newman-Keuls tests show that the 2 x 3 cell condition resulted in the longest task completion time and the most glances to it, and that both measures decreased as the number of cells decreased (Table 42). Means for the single cell panel were significantly different from the others, while there was no significant difference between the triple and 2 x 2 cell configurations. Linear regressions using the number of cells as the regressor showed significant correlations for both task completion time ( $r^2 = 0.987$ ) and the number of glances to the panels ( $r^2 = 0.975$ ). Clearly, the level of macroclutter, represented by the number of cells, influenced task performance in these two key measures.

The label type also had a significant effect on task completion time. The buttons labeled with randomly assigned letters of alphabet obviously took longer to find than the consecutively numbered buttons (Table 43). The analyses of variance in each simulated road type indicate no significant difference in the average length of glances to roadway between label types. There was, however, a significant interaction between these factors, as shown in Figure 36. Evidently, subjects took longer glances to the roadway while searching for a numbered button in the straight section; glances of similar length were taken in the curve section. Table 44 summarizes the analyses of variance for each macroclutter panel. The interaction between the type of simulated roadway and label type in the single cell configuration was apparently the source of the three-way interaction in the main analysis (Figure 37).

**Table 39. Analysis of variance summary (Comparisons of Expts. 1 & 2)**

Probability values less than 0.05 are shown.

**Dynamic Simulator Run Data**

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Experiment (E)	1				0.0372	0.0049
Task Category (T)	12	0.0001	0.0001	0.0001	0.0001	0.0001
E x T	12				0.0065	

**Table 40. Analysis of variance summary (Macroclutter experiment)**

Probability values less than 0.05 are shown.

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Gender (G)	1					
Road (R)	1	0.0164		0.0028		0.0403
Macroclutter Panel (P)	3	0.0001			0.0004	
Label Type (L)	1	0.0370				
R x P	3		0.0450			
R x L	1			0.0152		
P x L	3					
G x R	1					
G x P	3					
G x L	1					
R x P x L	3	0.0101				
G x R x P	3					
G x R x L	1					
G x P x L	3	0.0201				
G x R x P x L	3					

**Table 41. Newman-Keuls results for Simulated Roadway**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Roadway Type
A	4.193	64	Curves
B	3.635	64	Straight

**(b) Dependent Measure: Average Length of Glances to Roadway (s)**

Grouping	Mean	n	Roadway Type
A	0.883	64	Curves
B	0.732	64	Straight

**(c) Dependent Measure: Average Length of Glances to IP (s)**

Grouping	Mean	n	Roadway Type
A	0.958	64	Straight
B	0.879	64	Curves

**Table 42. Newman-Keuls results for Macroclutter Panel**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Panel Type
A	4.635	32	2 x 3
B	4.084	32	2 x 2
B	3.901	32	Triple
C	3.036	32	Single

**(b) Dependent Measure: Number of Glances to IP**

Grouping	Mean	n	Panel Type
A	2.167	32	2 x 3
A	1.906	32	2 x 2
A	1.859	32	Triple
B	1.406	32	Single

**Table 43. Newman-Keuls results for Label type (Task completion time)**

Means with the same letter are not significantly different.

Grouping	Mean	n	Label Type
A	4.048	64	Alphabet
B	3.781	64	Numerical

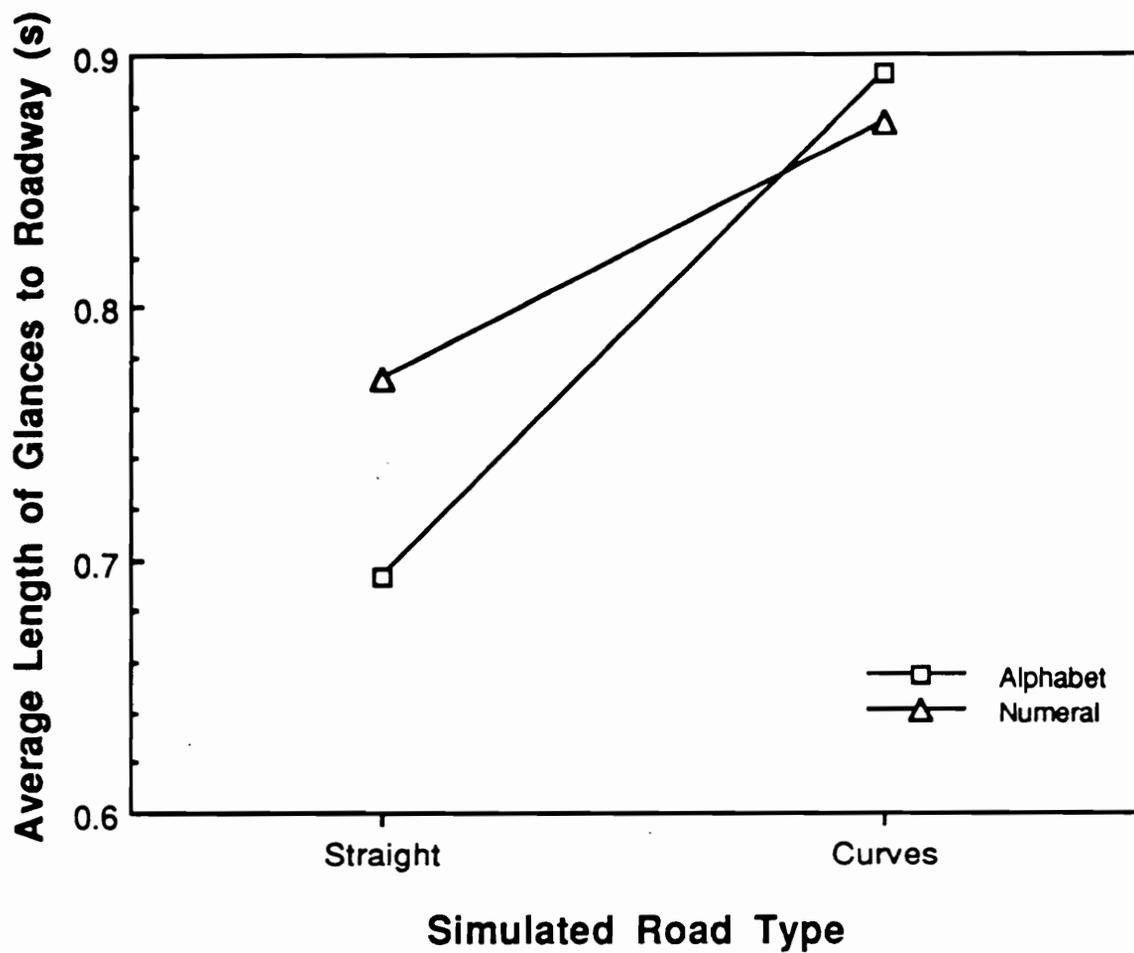


Figure 36. Interaction between Simulated Road type and Label type: Average length of glances to the roadway

**Table 44. Analyses of variance summary for each Macroclutter panel**

Dependent measure: Task completion time  
 Probability values less than 0.05 are shown.

Macroclutter Panel Type	Source						
	Gender (G)	Road (R)	G x R	Label Type (L)	G x L	R x L	G x R x L
Single				0.0033		0.0337	
Triple		0.0404					
2 x 2		0.0348					
2 x 3							

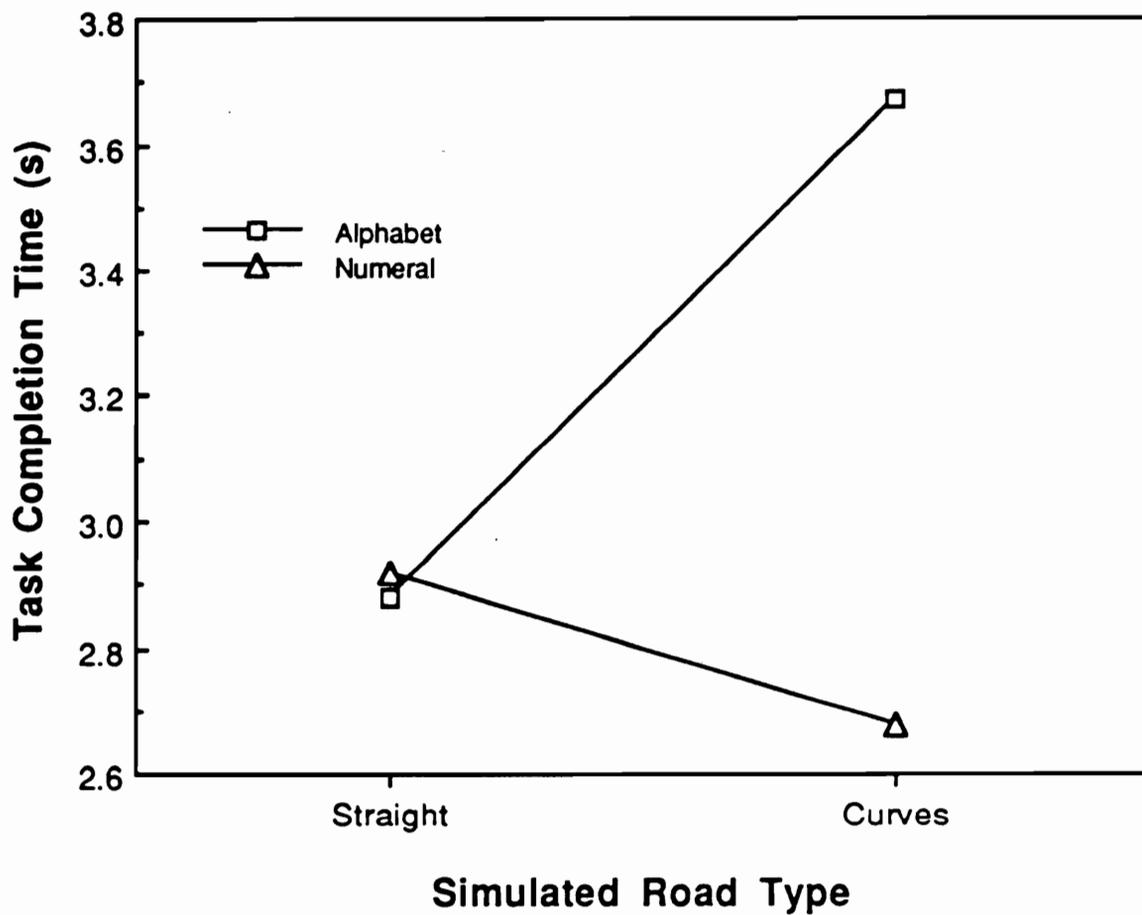


Figure 37. Interaction between Road type and Label type in Single Cell panel: Task completion time

Lastly, the panel means for the static simulator runs and the dynamic runs under the two roadway conditions ("straight means" denote the means under the straight roadway condition, whereas "curve means" denote the simulated driving condition with road curvature) are shown in Figures 38 through 40. As in previous comparisons, task completion times in the static simulator runs are shorter. Total glance times to the instrument (macroclutter) panels are longer, since tasks are completed in one continuous glance without any glance to the roadway.

### *Discussions (Experiment 2)*

The main purpose of this experiment was to investigate the effect of IP macroclutter on task performance. Although only four levels of macroclutter could be accommodated, to keep the duration of an experimental session under 2 hours, useful results were obtained with regard to the number of cells and type of labeling. As expected, the single cell configuration resulted in the fastest task performance, while the 2 x 3 configuration took longest and required the most glances. Obviously, the level of macroclutter, as represented by the number of cells, influenced the task complexity and had a substantial effect on task performance. The dramatic (over 50%) difference between the single cell and 2 x 3 configurations demonstrated this point.

It is equally important to note that a difference in task performance exists between consecutively labeled buttons and randomly labeled buttons. It took subjects approximately 7% longer to complete a task when searching for buttons with randomly assigned letters than for consecutively numbered buttons. This difference is obviously caused by drivers having to look for randomly assigned labels. Clearly, it is essential that various controls in instrument panels be labelled in a manner that is consistent and logical with users' expectations.

One implication of these findings is that there is a trade-off between the number of cells and multiple function assignment of their controls. On one hand, it would be better to reduce the level of IP macroclutter and thus the overall complexity of an IP. Use of a touch panel display, for example, would be an ideal solution, as it minimizes the level of macroclutter by employing multiple

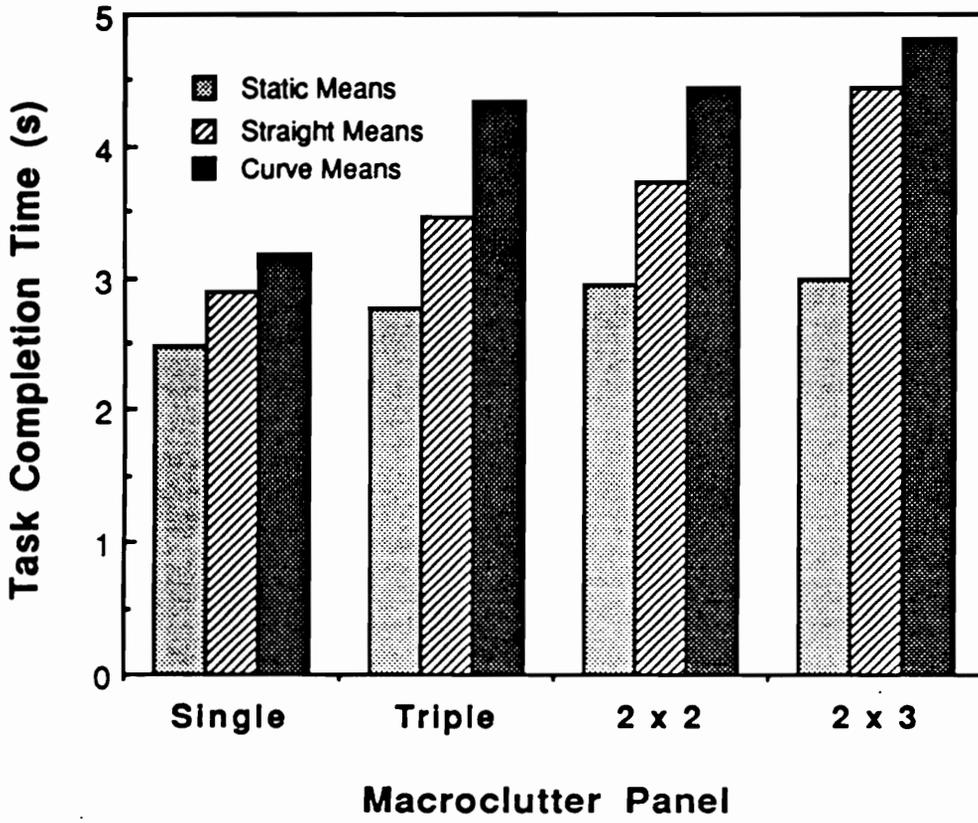


Figure 38. Comparisons of Macroclutter Panel means (Task completion time)

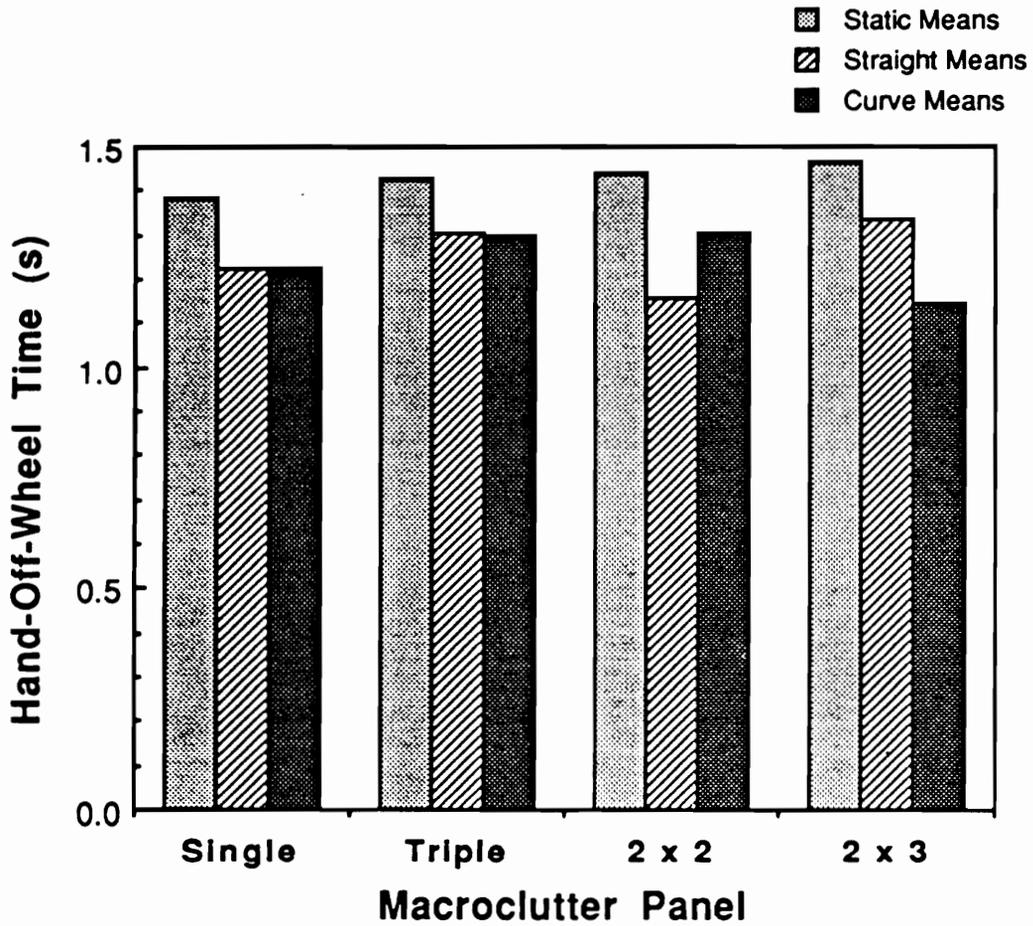


Figure 39. Comparisons of Macroclutter Panel means (Hand-off-wheel time)

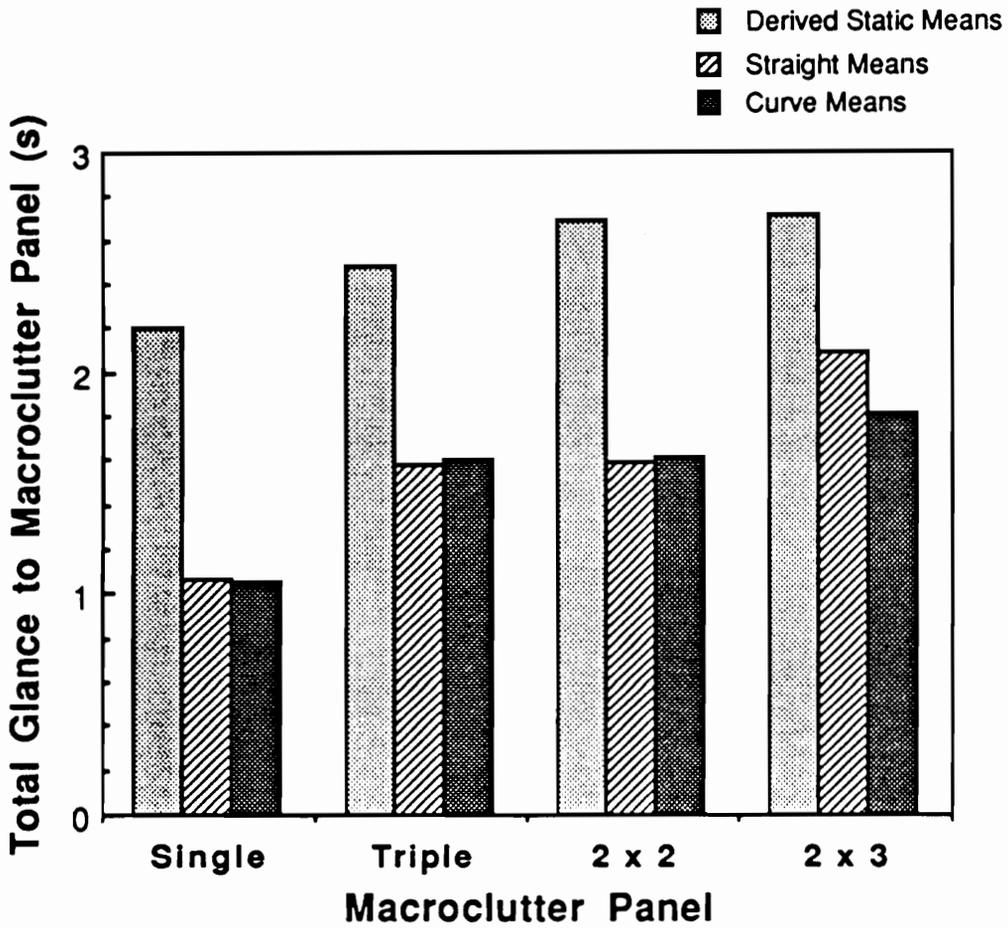


Figure 40. Comparisons of Macroclutter Panel means (Total glance time to IP)

control overlays. On the other hand, the use of multiple control overlays might increase both complexity and difficulty of individual tasks. For instance, lack of consistency in display format among control overlays for different tasks might confuse the user and result in slower task performance.

It is thus essential to find an optimum combination between the number of control cells (and their level of multifunctionality) and consistent labelling of individual controls. As the number of cockpit instruments increases, it is neither desirable or feasible to continue adding dedicated controls for each new function. One must, however, be careful not to multiply the number of functions assigned to the same control for IP space consideration.

Some of the issues involving touch panel displays, namely (micro)clutter within an instrument and labelling, were investigated in the following experiment.

### Experiment 3: Abbreviation/Microclutter Investigation

#### *Simulated touch panel display*

A 12-inch diagonal monochrome CRT display was mounted above the auxiliary instrument panel to simulate a touch panel display. The display was interfaced with an IBM PC microcomputer via a color/graphics display adapter, and its content was controlled by a BASICA program.

The number of controls displayed in the simulated touch panel was varied among (1) a single button (Figure 41), (2) a 2 x 2 array of buttons (Figure 42), and (3) a 3 x 3 array (Figure 43). During the experimental session, the shape of buttons was also varied equally between circle and square (both approximately 5/8 inch in width). Twenty-nine terms which may be found in the dashboard of future automobiles but which are not commonly used in the present automobiles were selected for this experiment, and two abbreviated labels were then created for each term (Table 45). The level of (micro)clutter within the simulated touch panel was thus varied by the number of buttons and the level of abbreviation in their labels.

#### *Procedure (Experiment 3)*

Eight subjects (4 female and 4 male) participated in this experiment. Their age varied from 18 to 23 years with a median age of 20 years (median number of years driving: 4).

At the beginning of an experimental session, subjects were given 5 minutes to become familiar with the labels for the simulated touch panel in their two abbreviated forms as well as in their fully spelled form. They were given the listing similar to that in Table 45 and instructed to memorize the association of the abbreviated labels with the fully-spelled ones. As the labels used in this experiment were uncommon for the present-day automobile, this five-minute orientation was intended to familiarize the subjects to a similar level.



Figure 41. Single button Touch Panel with auxiliary IP

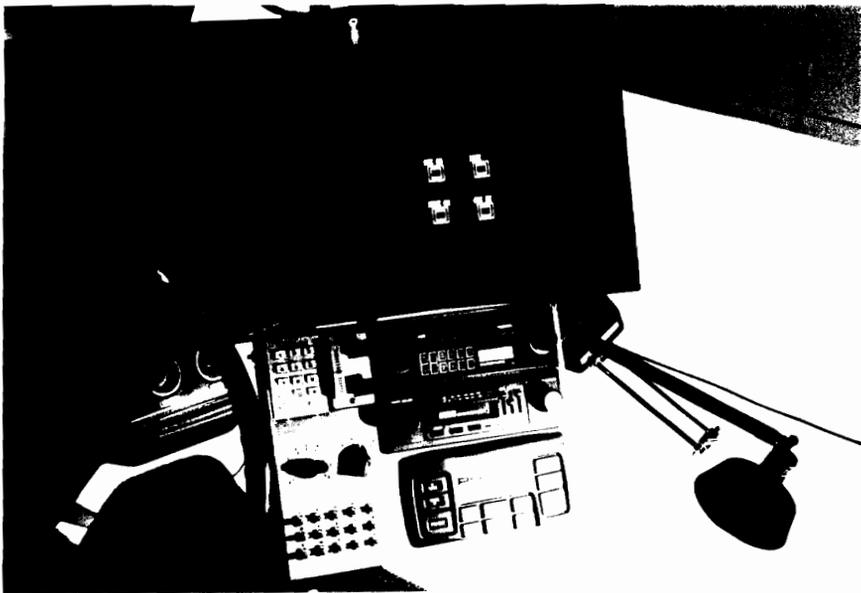


Figure 42. 2 x 2 Touch Panel with auxiliary IP



Figure 43. 3 x 3 Touch Panel with auxiliary IP

Table 45. List of Abbreviated labels

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1	ACTIVATE TWILIGHT SENTINEL	TWIL SENT	TWI-SENT
2	ACTIVATE HEAD-UP DISPLAY	HEAD-UP DISP	HUD ON
3	ACTIVATE SECURITY SYSTEM	SECURITY ON	SECRTY
4	ADJUST SEAT POSITION	ADJ SEAT	SEAT
5	ADJUST CLIMATE CONTROL	ADJ TEMP	TEMP
6	AREA TRAFFIC ADVISORY	AREA TRAF ADV	TRF ADV
7	AVERAGE MILES PER GALLON	AVG MI/GAL	AV MPG
8	COLLISION AVOIDANCE SONAR	COL AVD SONAR	SONAR
9	COMPUTE OPTIMUM ROUTE	COMP OPT RTE	OPT RT
10	DISPLAY TELEPHONE DIRECTORY	DISP TEL DIR	TEL DIR
11	DISTANCE TO DESTINATION	DIST TO GO	DIST
12	ELECTRONIC FREQUENCY SCAN	ELEC FREQ SCAN	SCAN

---

**Table 45 (Continued)**

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13	ENGAGE ANTI-LOCK BRAKING SYSTEM	ANTI-LOCK BRAKE	ABS ON
14	ENGAGE DRIVE- BY-WIRE	DRIVE BY-WIRE	DBW ON
15	ENGAGE FOUR-WHEEL STEERING	4-WHEEL STEER	4WS ON
16	ENGAGE RIDE CONTROL	RIDE CTRL	RIDE ON
17	ENTER PRESENT LOCATION	ENTER PRES LOC	PRES LOC
18	ENTERTAINMENT SYSTEM MENU	ENTERTAINMENTT	ENTRTMT
19	ESTIMATED TIME OF ARRIVAL	EST ARRIVAL	ETA
20	EXTENDED RANGE CRUISE	XR CRUISE	XR-CRS
21	GLOBAL POSITIONING SYSTEM	GLOB POS SYS	GPS
22	LONG- RANGE NAVIGATION	LNG-RANG NAV	LORAN
23	LOW TIRE PRESSURE	LO-TIRE PRES	LO TIRE
24	OUTSIDE AIR TEMPERATURE	OUTSIDE TEMP	OUT TEMP

---

**Table 45 (Continued)**

---

25	REAR COMPARTMENT AJAR	REAR COMP AJAR	REAR AJAR
26	REMAINING FUEL IN GALLON	REM FUEL (GAL)	REM GAL
27	REPORT SYSTEM DIAGNOSTICS	SYS DIAGN	DIAG
28	VERTICAL CLEARANCE CONTROL	VERT CLEAR CTRL	VERT CL
29	WEATHER ADVISORY RADIO	WEATH ADV	WEATH

---

After the five-minute familiarization of control labels, a static simulator run was given to familiarize subjects with the types of tasks to be performed, using both the simulated touch panel and the auxiliary IP, and to measure the task performance while not driving.

Subjects were then instructed to "drive" the simulator and to practice the tasks while driving. Following the practice, the dynamic simulator run, during which subject's task performance was measured, was initiated. Midway through this run, which lasted approximately one hour, subjects were offered a short break.

**Static simulator run** The static simulator run consisted of 18 tasks using the simulated touch panel and 15 tasks using the auxiliary IP (Table 46). Subjects were instructed to keep their hands on the steering wheel and their eyes on the roadway as if they were stopped at a traffic light. Their task completion time and hand-off-wheel time were measured.

**Dynamic simulator run** In the dynamic simulator run, 180 observations on the simulated touch panel tasks and 60 observations on the auxiliary IP tasks were made (Appendix F) while subjects maneuvered the driving simulator through the simulated route with road curvature previously used in Experiment 2. As in the previous experiments, subjects were instructed to maintain the simulated vehicle speed between 50 and 60 miles per hour, and they were occasionally asked to read and report the speed.

During the experimental session, subject's eye movements were recorded in a videotape, which was analyzed frame-by-frame later. Statistical analyses of the five dependent measures, i.e., task completion time, hand-off-wheel time, the number and average length of glances to IP, and the average length of glances to the roadway, were performed using the Statistical Analysis System on the University's IBM 3090 computer.

**Table 46. List of IP task categories (Experiment 3)**

<b>Task Category</b>	<b>Description</b>
Bot 1o3*	Bottom (Pontiac) radio. Press one of three buttons.
Bot 1o6*	Bottom (Pontiac) radio. Press one of six buttons.
Bot 1o12*	Bottom (Pontiac) radio. Press one of twelve buttons.
LEDC High*	LED Continuous mode. High accuracy adjustment.
LEDC Step*	LED Continuous mode. Step-wise adjustment.
MGE High*	Middle (Kraco) radio graphic equalizer. High accuracy adjustment.
MGE Low*	Middle (Kraco) radio graphic equalizer. Low accuracy adjustment.
PB Directed*	Pushbutton array. Button location directed.
PB 1o5+	Pushbutton array. Press one of five buttons (row).
RT 1o4S*	4-position rotary knob. Numeral selection.
RT 1o9S*	9-position rotary knob. Numeral selection.
Tel 11*	Telephone keypad. Dial 13 digits (long distance).
Top AMT°	Top (Sparkomatic) radio. Press AM/FM then tune.
Top Time°	Top (Sparkomatic) radio. Read present time.
Top 1o5*	Top (Sparkomatic) radio. Press one of five buttons.

+ denotes task categories included in Experiments 1

° denotes task categories included in Experiments 2

\* denotes task categories included in Experiments 1 and 2

**Simulated touch panel tasks** In observations of the simulated touch panel tasks, the front experimenter, immediately after displaying a new screen, called for a control label in an unabbreviated form and instructed the subject to "press" the target control button.

There were three main factors involved in the tasks using the simulated touch panel. (1) The control button(s) displayed in the touch panel were arranged as a single button, a 2 x 2 array, or a 3 x 3 array. (2) Twenty distinct terms were used as target labels; the other nine were used only as decoys. (3) The control labels in each screen were presented in single-line abbreviation, double-line abbreviation, or a fully spelled (triple-line) unabbreviated form. Additionally, the shape of control button(s) was varied between circle (labels 1 through 10) and square (labels 11 through 20). When the 2 x 2 array or the 3 x 3 array was presented, the position of the target label was distributed equally among all positions in the array.

A single observation was made for each combination of the three main factors, and the data were thus analyzed as a 3 x 20 x 3 full factorial within-subject design, involving 8 subjects. The effects of button shapes and target positions were also analyzed, separately from the main analysis.

**Auxiliary IP tasks** Fifteen task categories were selected for use in this experiment (Table 46) and four observations of each task category were randomly distributed among the simulate touch panel tasks. These data were analyzed for the effects of task categories and presentation order, both of which were expected to be significant as they were in the previous experiments.

### *Results (Experiment 3)*

**Simulated touch panel tasks** The effects of gender, touch panel type, abbreviation, and control label on the five dependent measures (task completion time, hand-off-wheel time, number of glances to the touch panel, and average lengths of glances to roadway and to the touch panel) were tested, and the results are shown in Table 47.

**Table 47. Analyses of variance summary (Abbreviation/microclutter)**

Probability values less than 0.05 are shown.

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Gender (G)	1					
Panel Type (P)	2	0.0001	0.0194		0.0001	0.0003
G x P	2					
Abbreviation (A)	2	0.0003			0.0039	
G x A	2					
Label (L)	19					
G x L	19					
P x A	4	0.0026		0.0240	0.0002	
G x P x A	4					
P x L	38					
G x P x L	38					
A x L	38	0.0108	0.0376		0.0157	0.0053
G x A x L	38					
P x A x L	76	0.0017			0.0046	
G x P x A x L	76					

The type of simulated touch panel, i.e., a single button, a 2 x 2 array of buttons, or a 3 x 3 array, had significant effects on four of the five dependent measures. The Newman-Keuls tests (Table 48) show that the single button resulted in the shortest times and the fewest glances in all four measures and was significantly different from the other touch panel configurations. In task completion time and the number of glances to the touch panel, the 3 x 3 array was significantly different from the 2 x 2 array, while they were similar in the hand-off-wheel time and average length of glances to the touch panel. Linear regressions for task completion time, and the number and average length of glances to the touch panel were performed using the number of controls as the regressor, and strong correlations ( $r^2 = 0.992, 0.979, 0.909$ , respectively) were found.

These results indicate that it took longer to complete a task with a 3 x 3 array of buttons because subjects looked at it more times than at a 2 x 2 array, and that the lengths of each glance were about the same in both arrays. The times to press the target button, once located, i.e., hand-off-wheel times, were about the same. In the single button configuration, on the other hand, as there were no decoys involved, subjects looked at the panel long enough to locate the target, perhaps to confirm the label, and press the button, thus resulting in the quickest response. The average length of glances to the roadway evidently remained constant, while the number of glances varied for the panel type.

The level of abbreviation also had significant effects on task completion time and the number of glances to the simulated touch panel. As the Newman-Keuls tests (Table 49) show, single-line abbreviations resulted in significantly shorter task completion time and significantly fewer glances. The hand-off-wheel time, the average lengths of glances to roadway and to the touch panel, on the other hand, did not change significantly. Evidently, it took fewer glances to recognize the target label in single-line abbreviation and thus less time to complete the task than in the double-line abbreviation or the fully spelled form. There was no significant difference between the double-line abbreviation and the fully spelled form.

**Table 48. Newman-Keuls results for Simulated Touch Panel type**  
Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Panel Type
A	5.970	479	3 x 3
B	4.163	480	2 x 2
C	2.989	479	1 x 1

**(b) Dependent Measure: Hand-Off-Wheel Time (s)**

A	1.348	480	2 x 2
A	1.346	479	3 x 3
B	1.224	479	1 x 1

**(c) Dependent Measure: Number of Glances to IP**

A	2.512	479	3 x 3
B	1.699	479	2 x 2
C	1.313	479	1 x 1

**(d) Dependent Measure: Average Length of Glances to IP (s)**

A	1.113	479	3 x 3
A	1.077	479	2 x 2
B	0.762	478	1 x 1

**Table 49. Newman-Keuls results for Abbreviation level**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Abbreviation
A	4.586	480	Full Term
A	4.465	479	Double-line
B	4.070	479	Single-line

**(b) Dependent Measure: Number of Glances to IP**

Grouping	Mean	n	Abbreviation
A	1.925	480	Full Term
A	1.895	479	Double-line
B	1.705	478	Single-line

There were no significant differences among the labels. Neither was there a significant effect of subject's gender. The data were thus reanalyzed as a 3 x 3 x 2 x 10 design, deleting gender as a factor and introducing the button shape (making the target label a within-button shape factor). The results of these analyses of variance are summarized in Table 50.

Analyses of variance for each simulated touch panel configuration were performed to examine the significant interactions involving button shape (Table 51). The interactions between the panel type and abbreviation in task completion time and the number of glances to the touch panel were straightforward. As shown in Table 51a and 51c, and Figures 44 and 45, abbreviation was a significant factor only in the 3 x 3 array; it had no significant effect in a single button in a 2 x 2 array.

In the average length of glances to the roadway, however, this interaction between the panel type and abbreviation became puzzling (Table 51b and Figure 46). There were peculiar interactions in 2 x 2 and 3 x 3 arrays, which resulted in the double-line abbreviation in a 2 x 2 array begin significantly different from the other two configurations. Similarly, the target label had a significant effect on the average length of glances to the touch panel only in a 2 x 2 array, which resulted in the significant interaction between the touch panel type and target labels.

Significant interactions between abbreviation and target labels in task completion time, the number and average length of glances to the touch panel were clarified by analyses of variance at each level of abbreviation and in each target label (Tables 52 through 55 and Figures 47 through 49). Evidently, when certain target labels were shown, the dependent measures varied in a manner different from the typical increasing trend. In task completion time (Figure 47), the double-line abbreviation of Label 13 ("ESTIMATED TIME OF ARRIVAL") evidently took longer perhaps because the abbreviation ("EST ARRIVAL") did not contain "TIME". In the number of glances to the touch panel (Figure 48), the double-line abbreviations of Label 9 ("ELECTRONIC FREQUENCY SCAN") and Label 10 ("ENGAGE ANTI-LOCK BRAKING SYSTEM") took longer (but likely for different reasons). As none of these terms used is particularly more obscure than others, the exact causes of these observations are unknown.

**Table 50. Analyses of variance summary (Abbreviation/microclutter)**

Probability values less than 0.05 are shown.

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Panel Type (P)	2	0.0001	0.0196		0.0001	0.0002
Abbreviation (A)	2	0.0003			0.0033	
Button Shape (B)	1					
Label/Shape (L/B)	18					
P x A	4	0.0033		0.0186	0.0002	
P x B	2	0.0330				
P x L/B	36					0.0389
A x B	2		0.0222			
A x L/B	36	0.0062			0.0089	0.0099
P x A x B	4					0.0007
P x A x L/B	72	0.0009			0.0054	

**Table 51. Analyses of variance summary for each Simulated Touch Panel**

Probability values less than 0.05 are shown.

**(a) Dependent Measure: Task Completion Time**

	Source		
Panel Type	1 x 1	2 x 2	3 x 3
Abbreviation (A)			0.0025
Button Shape (B)			
Label/Shape (L/B)			
A x B			
A x L/B		0.0066	0.0038

**(b) Dependent Measure: Average Length of Glances to Roadway**

	Source		
Panel Type	1 x 1	2 x 2	3 x 3
Abbreviation (A)		0.0186	
Button Shape (B)			
Label/Shape (L/B)			
A x B			
A x L/B			

**Table 51 (Continued)****(c) Dependent Measure: Number of Glances to IP**

Panel Type	Source		
	1 x 1	2 x 2	3 x 3
Abbreviation (A)			0.0009
Button Shape (B)			
Label/Shape (L/B)			
A x B			
A x L/B		0.0165	0.0092

**(d) Dependent Measure: Average Length of Glances to IP**

Panel Type	Source		
	1 x 1	2 x 2	3 x 3
Abbreviation (A)			
Button Shape (B)			
Label/Shape (L/B)		0.0398	
A x B		0.0009	
A x L/B		0.0355	

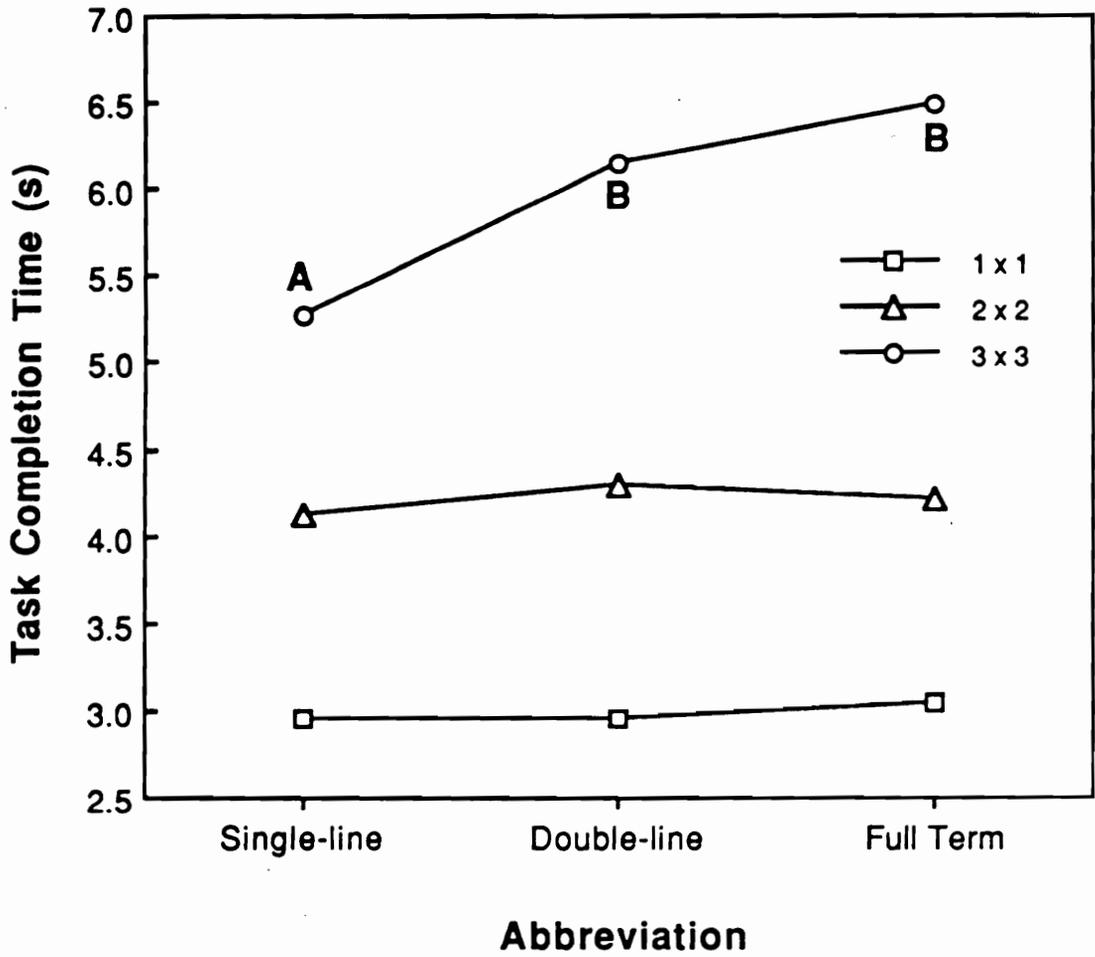


Figure 44. Interaction between Abbreviation and Touch Panel type: Task completion time

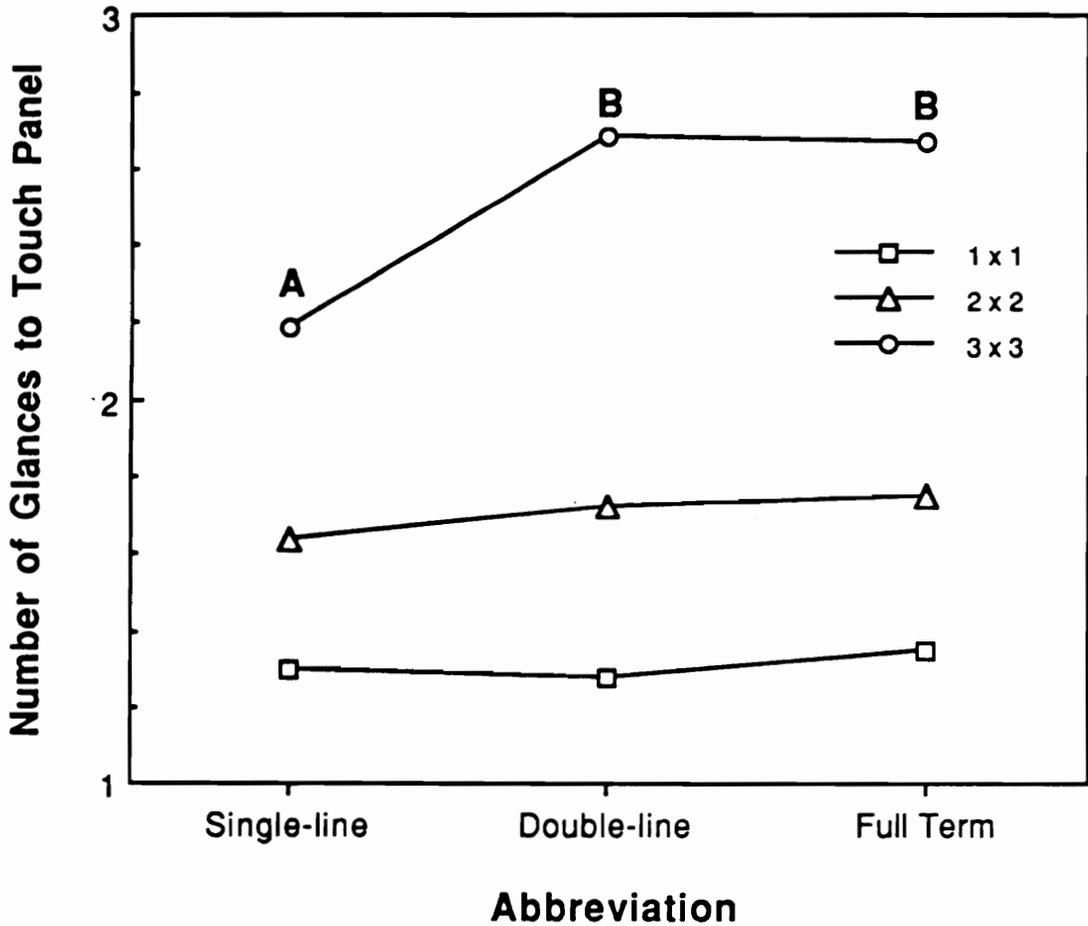


Figure 45. Interaction between Abbreviation and Touch Panel type: Number of glances to Touch Panel

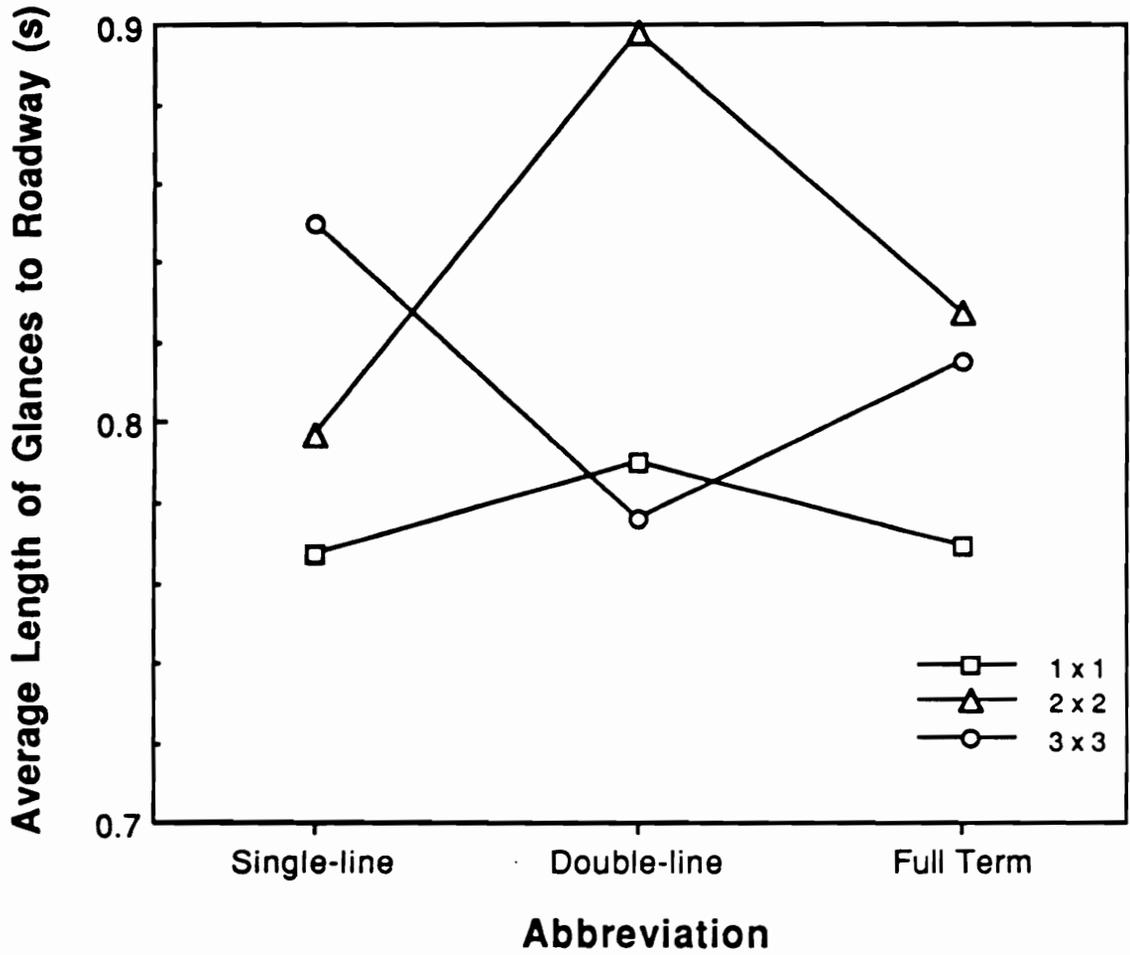


Figure 46. Interaction between Abbreviation and Touch Panel type: Average length of glances to the roadway

**Table 52. Analyses of variance summary for each Abbreviation level**  
 Probability values less than 0.05 are shown.

**(a) Dependent Measure: Task Completion Time**

Abbreviation Level	Source		
	Single-line	Double-line	Full Term
Panel Type (P)	0.0001	0.0001	0.0001
Button Shape (B)			
Label/Shape (L/B)			0.0020
P x B			
P x L		0.0026	0.0004

**(b) Dependent Measure: Hand-Off-Wheel Time**

Abbreviation Level	Source		
	Single-line	Double-line	Full Term
Panel Type (P)			0.0069
Button Shape (B)			
Label/Shape (L/B)			
P x B			
P x L/B			

**Table 52 (Continued)**

(c) Dependent Measure: Number of Glances to IP

Abbreviation Level	Source		
	Single-line	Double-line	Full Term
Panel Type (P)	0.0001	0.0001	0.0001
Button Shape (B)			
Label/Shape (L/B)		0.0246	0.0168
P x B			
P x L/B		0.0220	0.0026

(d) Dependent Measure: Average Length of Glances to IP

Abbreviation Level	Source		
	Single-line	Double-line	Full Term
Panel Type (P)	0.0002	0.0013	0.0006
Button Shape (B)		0.0455	
Label/Shape (L/B)		0.0137	
P x B	0.0080	0.0341	0.0126
P x L/B		0.0446	

**Table 53. Analyses of variance summary for each Target label**

Dependent measure: Task completion time  
Probability values less than 0.05 are shown.

Target Label	Source		
	Panel Type (P)	Abbreviation (A)	P x A
1	0.0006	0.0251	0.0039
2	0.0001	0.0060	0.0030
3	0.0004		
4	0.0001	0.0058	0.0350
5	0.0001	0.0028	0.0001
6	0.0001		0.0001
7	0.0001		
8	0.0001		
9	0.0070		
10	0.0005		
11	0.0007		
12	0.0001		
13	0.0010	0.0280	
14	0.0005		
15	0.0006		
16	0.0003		
17	0.0022		
18	0.0001		
19	0.0174		
20	0.0001		

**Table 54. Analyses of variance summary for each Target label**

Dependent measure: Average length of glances to Touch Panel  
 Probability values less than 0.05 are shown.

Target Label	Source		
	Panel Type (P)	Abbreviation (A)	P x A
1	0.0064		
2	0.0074		
3	0.0008	0.0292	
4			
5	0.0043		
6	0.0027		
7	0.0072		
8	0.0104		
9	0.0004	0.0360	
10	0.0104	0.0170	
11	0.0221		
12	0.0012		
13	0.0300		
14	0.0192		
15	0.0003	0.0491	
16	0.0114		
17	0.0167		
18	0.0085		
19	0.0230		0.0230
20	0.0093		0.0324

**Table 55. Analyses of variance summary for each Target label**

Dependent measure: Number of glances to Touch Panel  
Probability values less than 0.05 are shown.

Target Label	Source		
	Panel Type (P)	Abbreviation (A)	P x A
1	0.0001	0.0228	0.0038
2	0.0003	0.0013	0.0126
3	0.0005		
4	0.0039	0.0359	0.0031
5	0.0001	0.0373	0.0007
6	0.0001		
7	0.0001		
8	0.0002		
9	0.0111	0.0140	
10	0.0003	0.0213	0.0089
11	0.0001		
12	0.0002		
13	0.0001	0.0255	
14	0.0004		
15	0.0008		
16	0.0002		
17	0.0023		
18	0.0002		
19	0.0036		
20	0.0001		

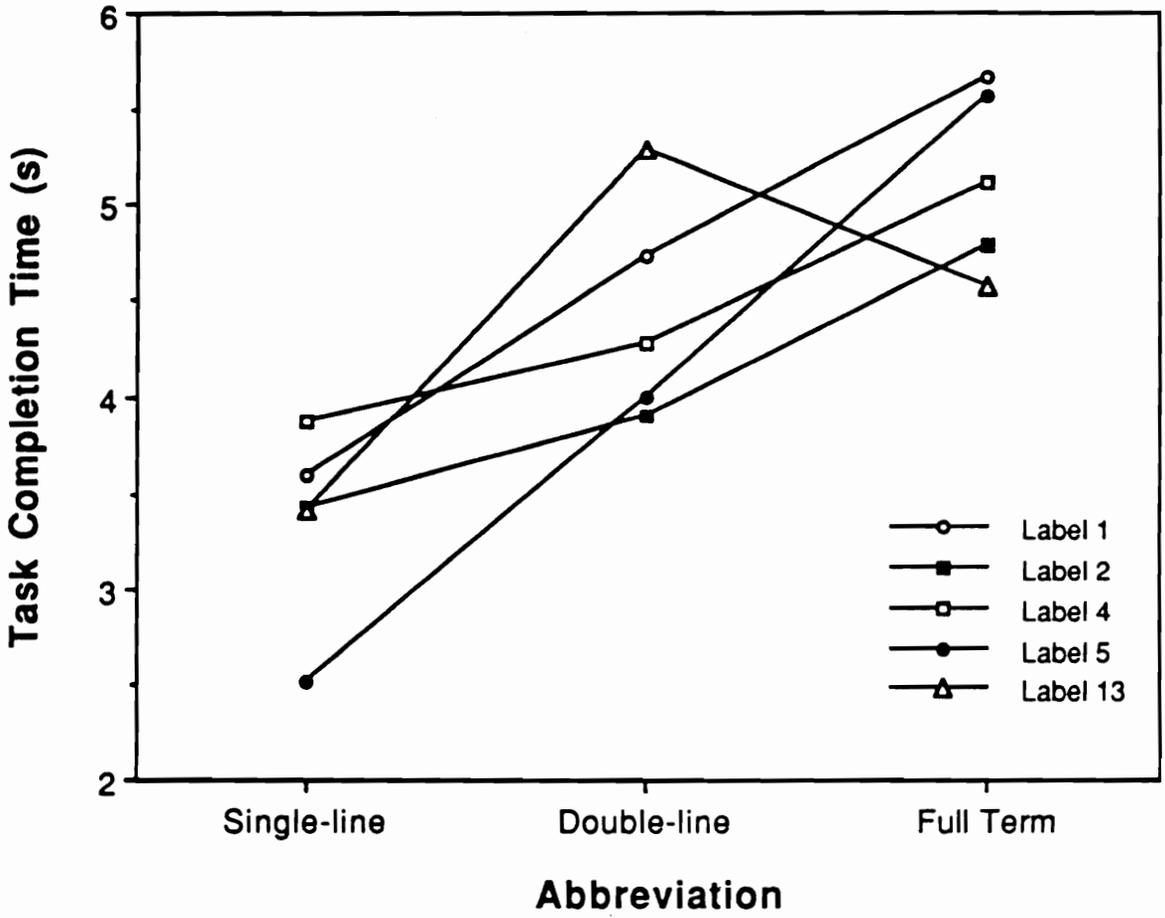


Figure 47. Interaction between Abbreviation and Target label: Task completion time

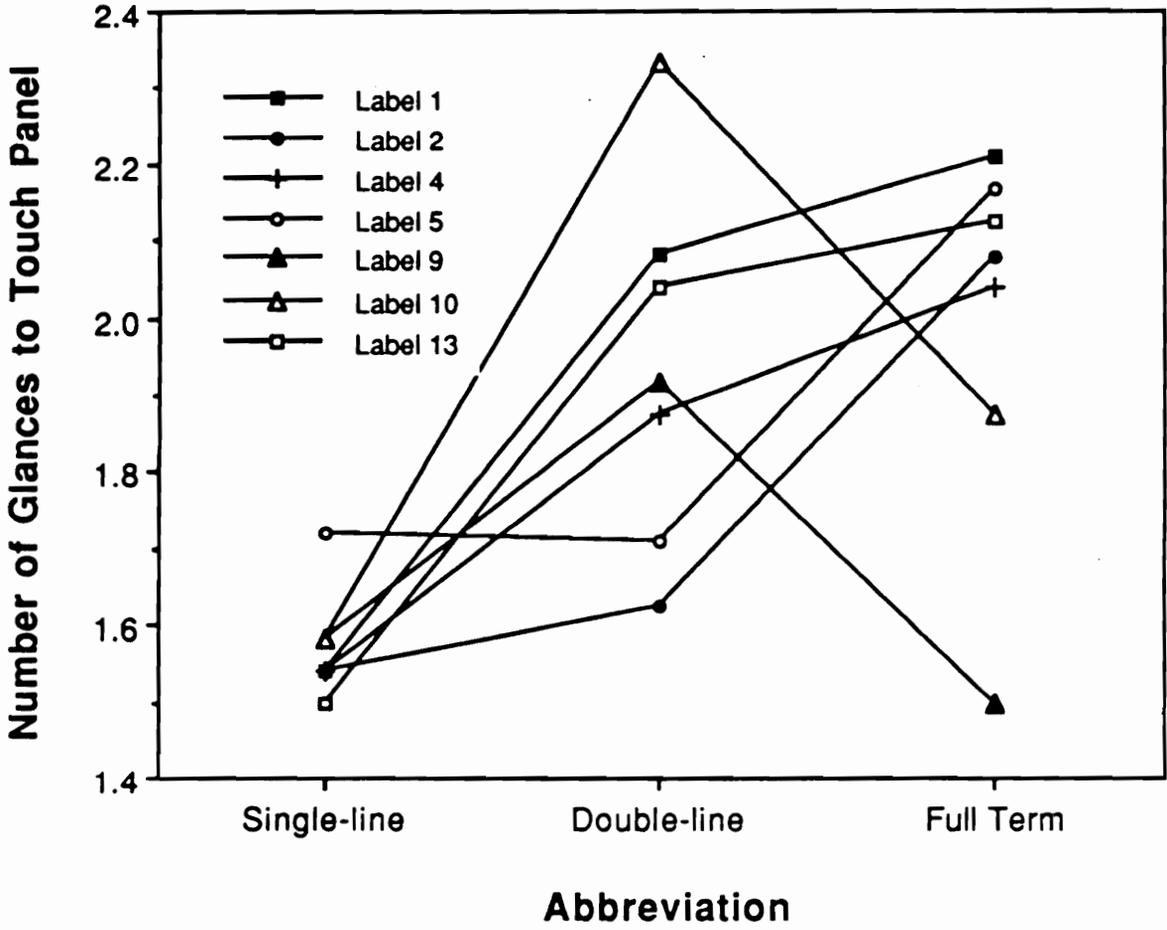


Figure 48. Interaction between Abbreviation and Target label: Number of glances to Touch Panel

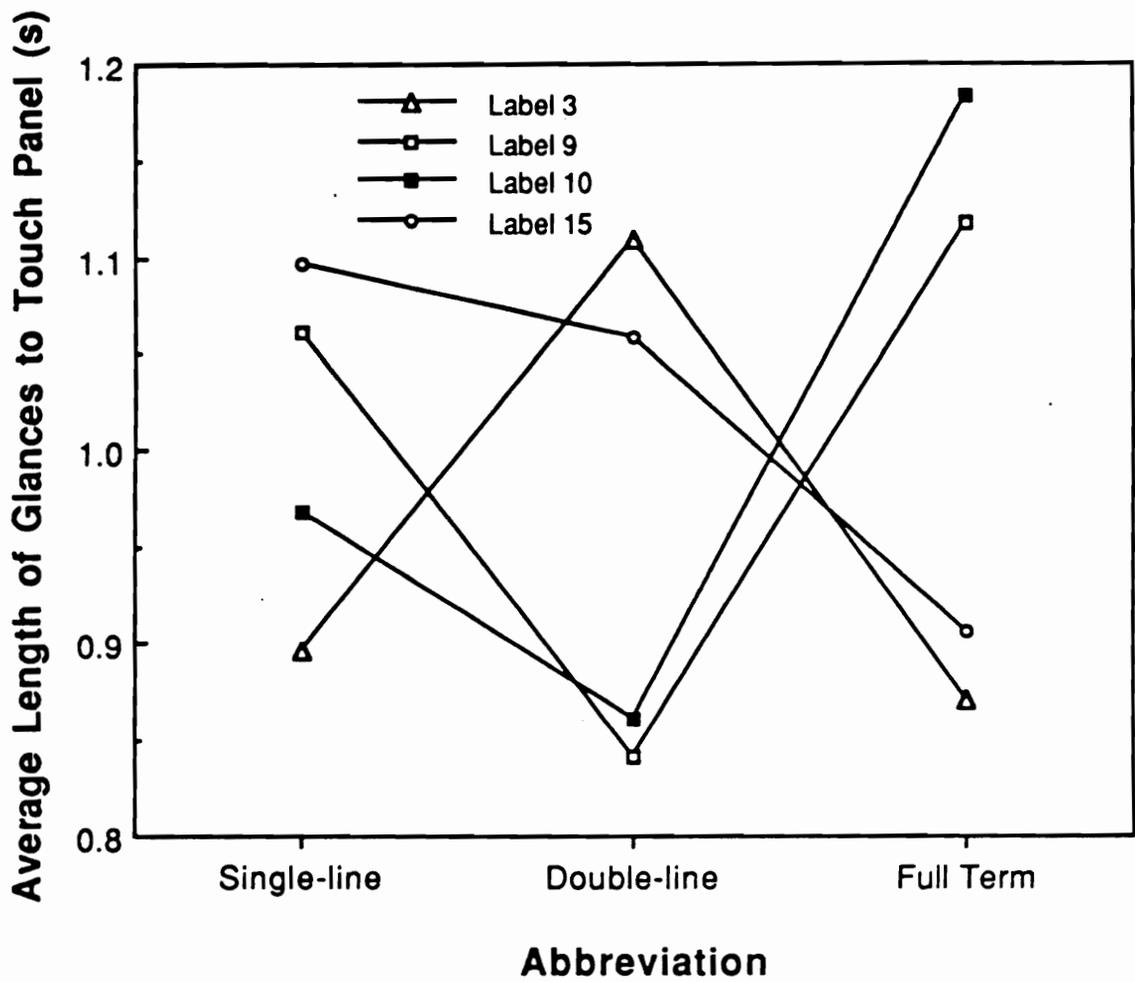


Figure 49. Interaction between Abbreviation and Target label: Average length of glances to Touch Panel

While causes of the interactions between the touch panel button shape and panel type (in task completion time, Table 51a) and between the button shape and abbreviation (in hand-off-wheel time, Table 52b) could not be determined, the significant three-way interaction involving these factors in the average length of glances to the touch panel was attributed to the interaction between abbreviation and the button shape in a 2 x 2 array (Tables 51d and 52d, and Figure 50).

The significant three-way interactions among touch panel type, abbreviation, and target labels in task completion time and the number of glances to the touch panel can be best explained in Figures 51 through 56. Table 53 shows that there were significant interactions between panel type and abbreviation with five of the target labels. Plots of labels 5 and 6 (Figures 51 and 52) clearly show the difference in the effect of abbreviation in a 3 x 3 panel. Figures 53 through 56 show the similar trend in the number of glances to the touch panel.

The data from the 2 x 2 array and 3 x 3 array of the simulated touch panel were analyzed separately for the effect of target position. For the analyses of variance, means at each target position were calculated by summing across target labels. The data from the 2 x 2 array were thus analyzed as a 3 x 4 within-subject design, while the data from the 3 x 3 array formed a 3 x 9 within-subject design (Table 56).

In addition to the significant effect of abbreviation in each panel type (already discussed), the target position was found to be a significant factor in certain dependent measures. The results of Newman-Keuls test for the 2 x 2 panel (Table 57) show a significant difference between positions 1 and 4. Both the hand-off-wheel time and average length of glances to the touch panel appear to be related to distance from the driver's forward line of sight (Figure 57). While the hand-off-wheel time increased with the diagonal distance, the average length of glances to the touch panel increased with the horizontal distance (the positions on the left-hand side required shorter glances than those on the right-hand side).

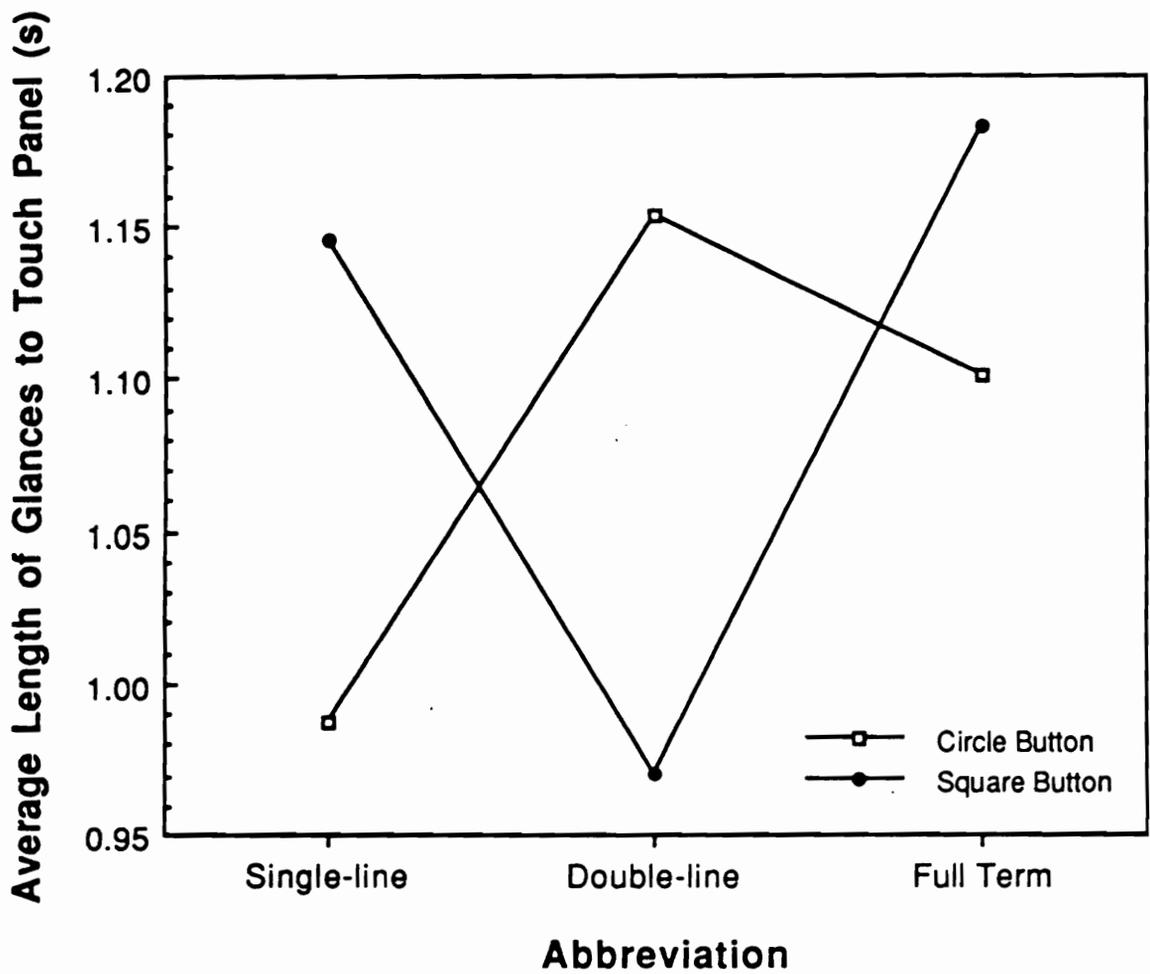


Figure 50. Interaction between Abbreviation and Button Shape in 2 x 2 Panel: Average length of glances to Touch Panel

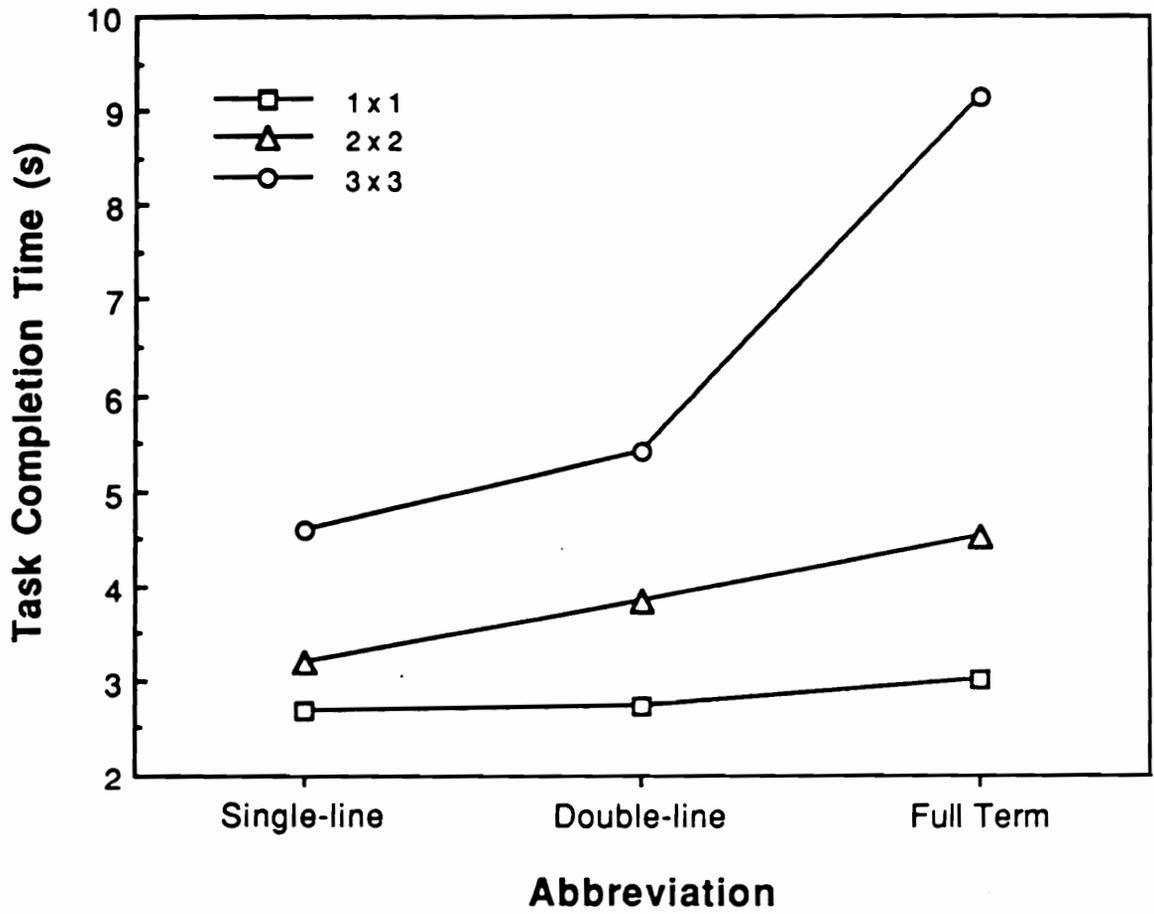


Figure 51. Interaction between Abbreviation and Touch Panel type in Label 5: Task completion time

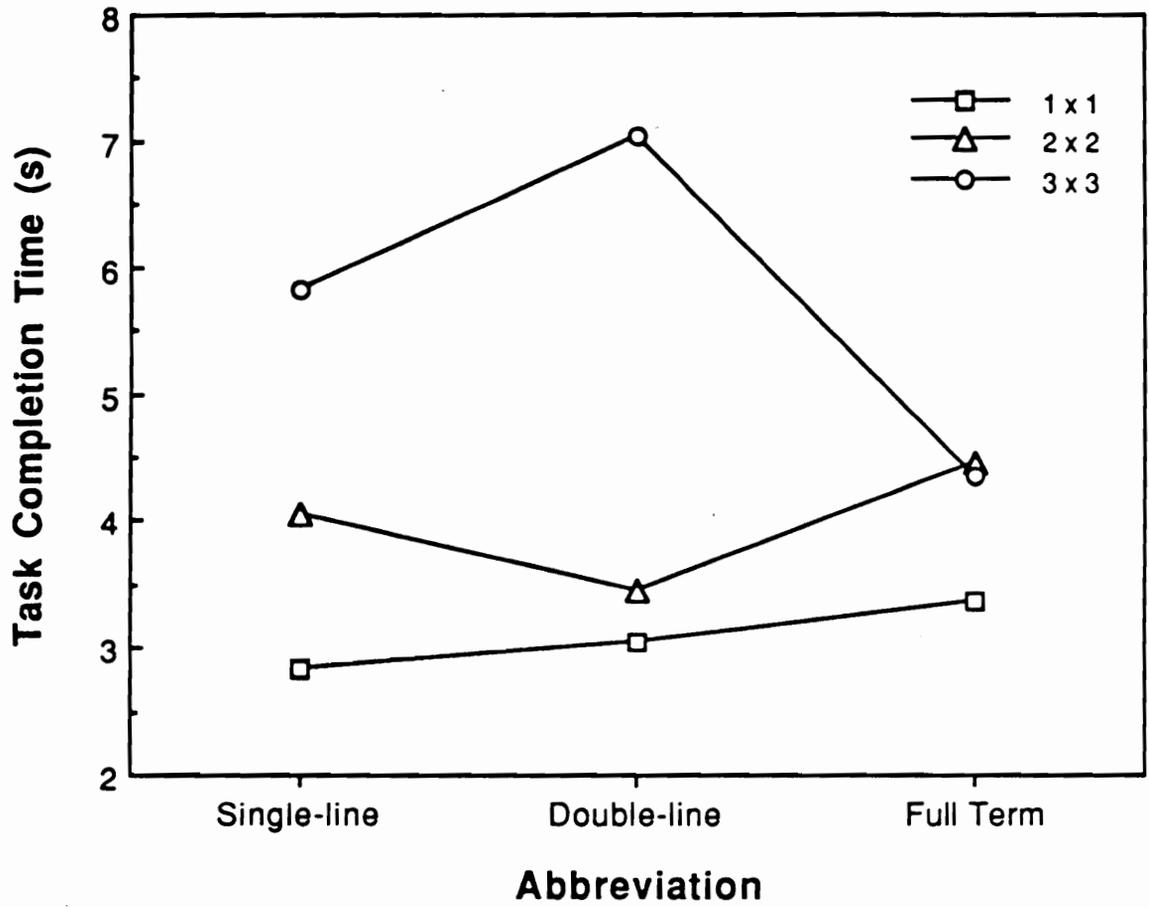


Figure 52. Interaction between Abbreviation and Touch Panel type in Label 6: Task completion time

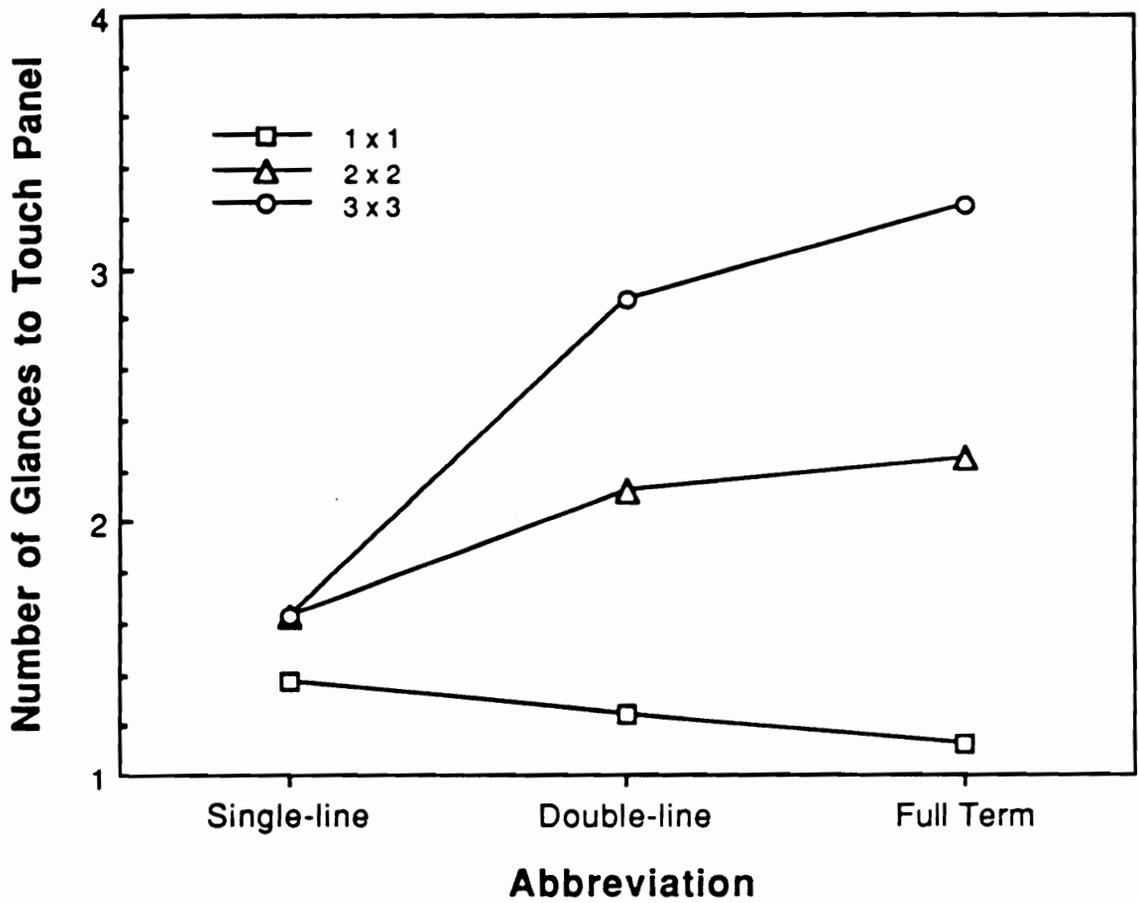


Figure 53. Interaction between Abbreviation and Touch Panel type in Label 1: Number of glances to Touch Panel

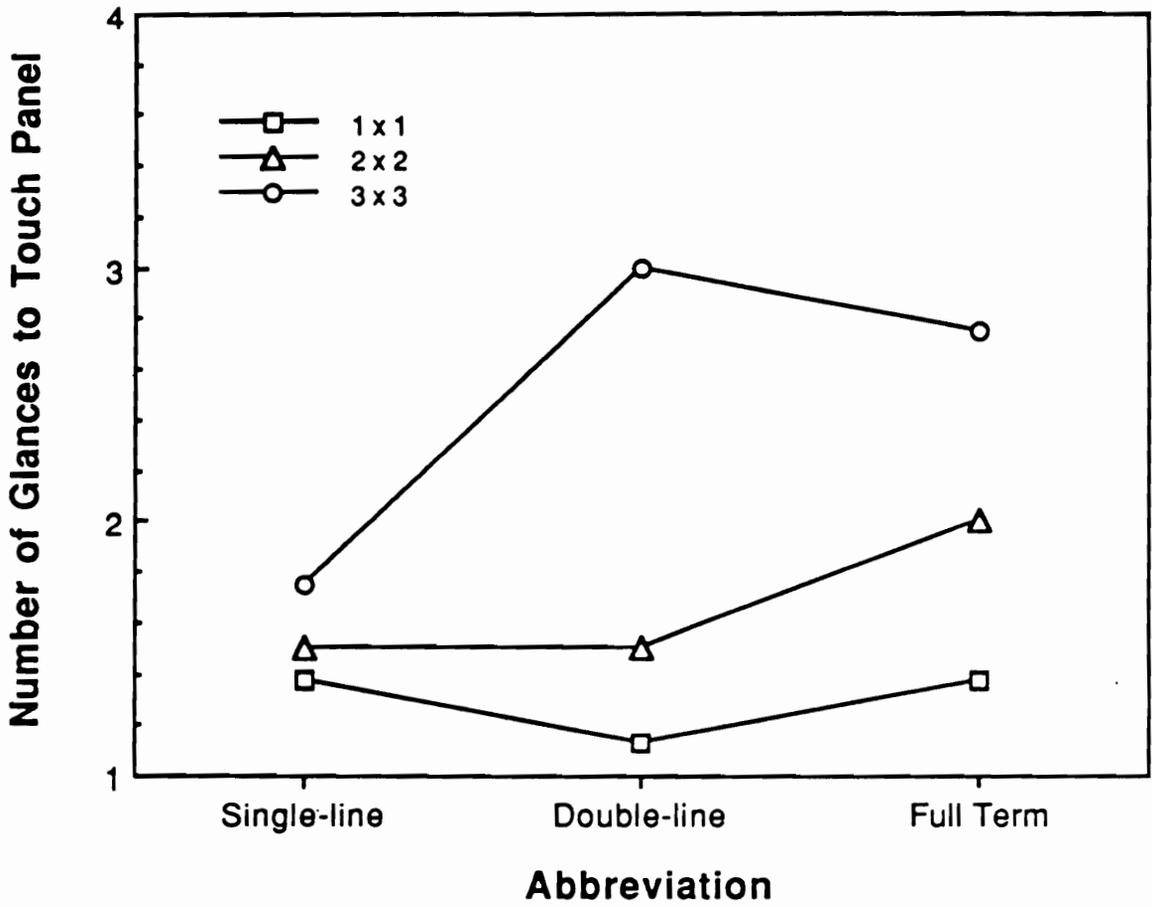


Figure 54. Interaction between Abbreviation and Touch Panel type in Label 4: Number of glances to Touch Panel

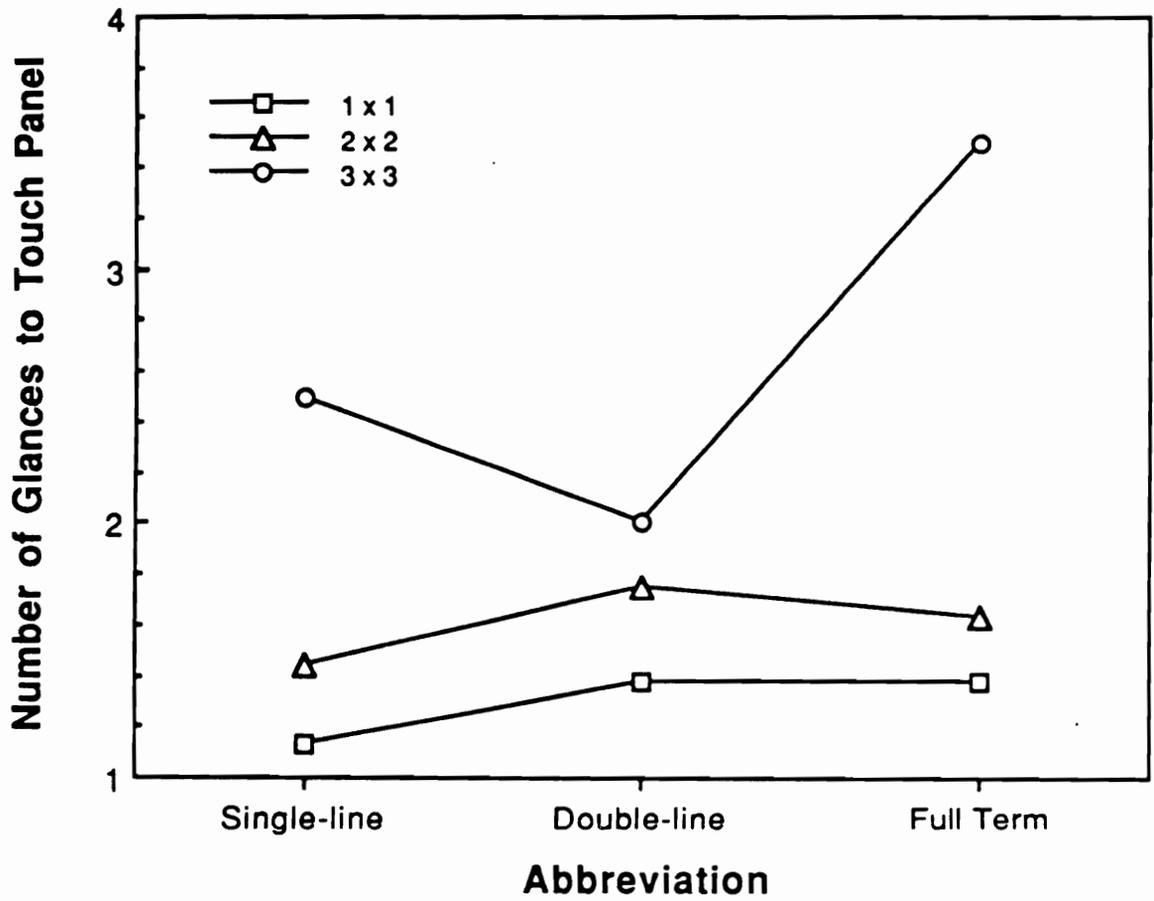


Figure 55. Interaction between Abbreviation and Touch Panel type in Label 5: Number of glances to Touch Panel

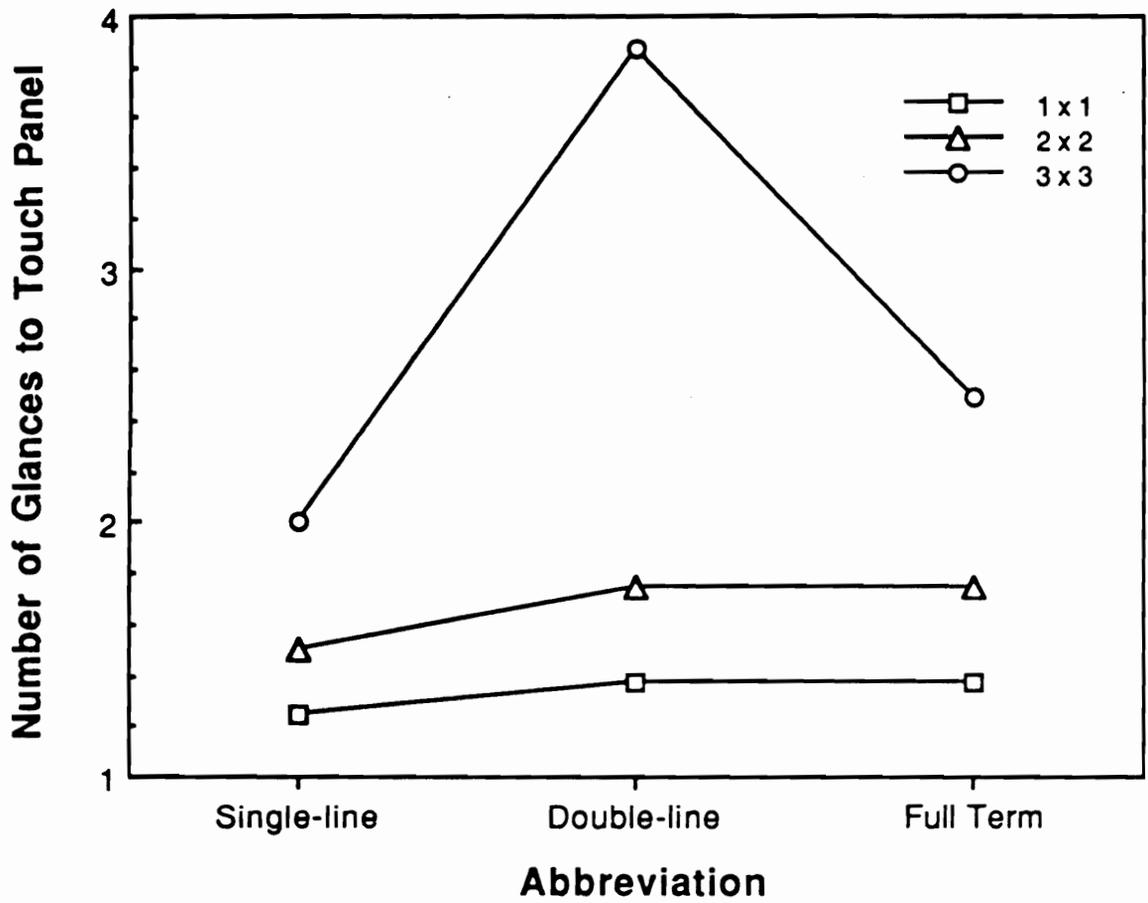


Figure 56. Interaction between Abbreviation and Touch Panel type in Label 10: Number of glances to Touch Panel

**Table 56. Analyses of variance summary for 2 x 2 and 3 x 3 panels**

Probability values less than 0.05 are shown.

2 x 2 Panel		Dependent Measure				
Source	df	Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Abbreviation (A)	2			0.0343		
Target Position (T)	3		0.0089			0.0010
A x T	6					

3 x 3 Panel		Dependent Measure				
Source	df	Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Abbreviation (A)	2	0.0019			0.0012	
Target Position (T)	8	0.0378	0.0438		0.0042	
A x T	16					

**Table 57. Newman-Keuls results for Target Position in 2 x 2 Panel**

Means with the same letter are not significantly different

**(a) Dependent Measure: Hand-Off-Wheel Time (s)**

Grouping	Mean	n	Target Position
A	1.434	24	4
A B	1.363	24	3
A B	1.344	24	2
B	1.246	24	1

**(b) Dependent Measure: Average Length of Glances to IP (s)**

Grouping	Mean	n	Target Position
A	1.207	24	4
A B	1.117	24	2
B	0.995	24	1
B	0.990	24	3

Hand-Off-Wheel Time (s)

---

Average Length of Glances to IP (s)

1.25	1.34
0.995	1.12
1.36	1.43
0.990	1.21

Figure 57. Target position means in 2 x 2 Panel

In the 3 x 3 panel, there were also significant differences between positions. In the number of glances to the touch panel, the most glances were made to the positions (3, 6, and 9) in the column which is furthest from boresight (Table 58). Positions 1, 4, and 7 in the closest column required the least number of glances (Figure 58). It should be noted that in both panel configurations, the differences between the maximum and the minimum are about 20%.

**Auxiliary IP tasks** The analyses of variance in the five dependent measures are summarized in Table 59. As expected, task categories were found to have significant effects on all five dependent measures. The results of Newman-Keuls tests are shown in Tables 60 through 64. The presentation order, i.e., the first observation of a given task category is assigned 1 while the fourth and last observation 4, also had significant effects on four of the dependent measures. As shown in Table 65, the first observations were significantly longer in task completion time, hand-off-wheel time, and the number of glances to the touch panel; the average length of glances to the touch panel was, however, shorter. The Newman-Keuls results in task completion and hand-off-wheel times are similar to those in Experiment 2.

Significant interactions were found between task categories and the presentation order in task completion and hand-off-wheel times, the average length of glances to roadway, and the number of glances to IP. These results are similar to Experiment 2. The analyses of variance in each task category (Tables 66 through 69) show the task categories in which the presentation order was found to be a significant factor.

The dependent measures were usually longest or greatest in the first observation and decreased in the later observations. Figures 59 through 61 show that certain task category changes in the later observations did not follow the same trend. In the average length of glances to the roadway, this interaction is caused solely by the significant effect of presentation order in task category MGE Low.

**Table 58. Newman-Keuls results for Target Position in 3 x 3 Panel**

Means with the same letter are not significantly different

**(a) Dependent Measure: Hand-Off-Wheel Time (s)**

Grouping	Mean	n	Target Position
A	1.541	24	8
A B	1.387	24	6
A B	1.374	24	1
A B	1.368	24	3
A B	1.354	24	9
A B	1.306	24	5
A B	1.295	24	2
B	1.246	24	7
B	1.226	24	4

**(b) Dependent Measure: Number of Glances to IP**

Grouping	Mean	n	Target Position
A	2.889	24	6
A B	2.792	24	9
A B	2.701	24	3
A B C	2.646	24	8
A B C	2.451	24	5
A B C	2.382	24	2
A B C	2.375	24	7
B C	2.181	24	1
C	2.083	24	4

Hand-Off-Wheel Time (s)

Number of Glances to IP

1.37 2.18	1.29 2.38	1.37 2.70
1.23 2.08	1.31 2.45	1.39 2.89
1.25 2.38	1.54 2.65	1.35 2.79

Figure 58. Target position means in 3 x 3 Panel

Table 59. Analyses of variance summary (Experiment 3 IP tasks)

Probability values less than 0.05 are shown.

Source	df	Dependent Measure				
		Task Completion Time	Hand-Off Wheel Time	Average Length of Glances to Roadway	Number of Glances to IP	Average Length of Glances to IP
Gender (G)	1					
Task Category (T)	14	0.0001	0.0001	0.0001	0.0001	0.0001
Presentation Order (O)	3	0.0006	0.0192		0.0001	0.0161
G x T	14		0.0367			
G x O	3	0.0418			0.0291	
T x O	42	0.0258	0.0139	0.0061	0.0002	
G x T x O	42			0.0289		

**Table 60. Newman-Keuls results for IP task category**

Dependent measure: Task completion time (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	13.503	8	Top AMT
B	12.102	8	Telephone 11
C	7.000	8	LEDC High
C D	6.370	8	MGE High
C D E	5.866	8	Bot 1o12
D E F	5.216	8	RT 1o9S
D E F	5.070	8	Bot 1o6
D E F	4.910	8	LEDC Step
D E F	4.682	8	Top Time
E F	4.379	8	PB 1o5
F	3.831	8	Bot 1o3
F	3.731	8	MGE Low
F	3.709	8	Top 1o5
F	3.587	8	RT 1o4S
F	3.177	8	PB Directed

**Table 61. Newman-Keuls results for IP task category**

Dependent measure: Hand-off-wheel time (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	11.172	8	Top AMT
B	9.586	8	Telephone 11
C	5.175	8	LEDC High
D	4.053	8	MGE High
D E	3.475	8	LEDC Step
E F	2.765	8	RT 1o9S
F	2.362	8	MGE Low
F	2.118	8	Bot 1o6
F	2.092	8	RT 1o4S
F	1.884	8	Top Time
F	1.828	8	Bot 1o12
F	1.709	8	Bot 1o3
F	1.626	8	Top 1o5
F	1.565	8	PB 1o5
F	1.525	8	PB Directed

**Table 62. Newman-Keuls results for IP task category**

Dependent measure: Average length of glances to the roadway (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	1.924	8	LEDC Step
A	1.893	8	MGE High
B	1.347	8	MGE Low
B	1.152	8	Bot 1o12
B	1.102	8	Bot 1o6
B	1.096	8	PB Directed
B	1.002	8	RT 1o9S
B	0.972	8	PB 1o5
B	0.972	8	Top Time
B	0.972	8	Telephone 11
B	0.970	8	Bot 1o3
B	0.950	8	Top AMT
B	0.914	8	RT 1o4S
B	0.898	8	Top 1o5
B	0.771	8	LEDC High

**Table 63. Newman-Keuls results for IP task category**

Dependent measure: Number of glances to IP  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	5.562	8	Top AMT
B	4.969	8	Telephone 11
C	2.844	8	LEDC High
D	1.938	8	RT 1o9S
D	1.906	8	Bot 1o12
D	1.719	8	Top Time
D	1.594	8	Bot 1o6
D	1.594	8	PB 1o5
D	1.500	8	RT 1o4S
D	1.488	8	MGE High
D	1.469	8	LEDC Step
D	1.406	8	Top 1o5
D	1.406	8	Bot 1o3
D	1.250	8	PB Directed
D	1.094	8	MGE Low

**Table 64. Newman-Keuls results for IP task category**

Dependent measure: Average length of glances to IP (s)  
 Means with the same letter are not significantly different.

Grouping	Mean	n	Task Category
A	1.262	8	Bot 1o6
A B	1.201	8	Top Time
A B	1.198	8	Bot 1o12
A B	1.180	8	LEDC High
A B C	1.058	8	Telephone 11
A B C	1.041	8	RT 1o9S
A B C	1.039	8	Top 1o5
A B C	1.008	8	Top AMT
A B C	0.995	8	PB 1o5
B C	0.880	8	RT 1o4S
B C	0.854	8	Bot 1o3
B C	0.841	8	MGE High
C	0.800	8	MGE Low
C	0.783	8	PB Directed
C	0.734	8	LEDC Step

**Table 65. Newman-Keuls results for Presentation Order**

Means with the same letter are not significantly different.

**(a) Dependent Measure: Task Completion Time (s)**

Grouping	Mean	n	Presentation Order
A	6.628	120	1
B	5.802	120	2
B	5.714	119	3
B	5.130	119	4

**(b) Dependent Measure: Hand-Off-Wheel Time (s)**

A	3.835	120	1
A B	3.609	119	2
A B	3.609	120	3
B	3.091	120	4

**(c) Dependent Measure: Number of Glances to IP**

A	2.400	120	1
B	2.150	120	3
B	2.080	119	2
C	1.833	120	4

**(d) Dependent Measure: Average Length of Glances to IP (s)**

A	1.066	120	4
A B	1.005	120	3
A B	0.989	119	2
B	0.907	119	1

Table 66. Analyses of variance summary for each IP task category

Dependent measure: Task completion time  
 Probability values less than 0.05 are shown.

Task Category	Source		
	Gender (G)	Presentation Order (O)	G x O
Bot 1o3			
Bot 1o6		0.0449	
Bot 1o12			
LEDC High		0.0060	
LEDC Step			
MGE High			
MGE Low			
PB Directed			
PB 1o5			
RT 1o4S		0.0021	
RT 1o9S			
Telephone 11			
Top AMT			
Top Time			
Top 1o5			

**Table 67. Analyses of variance summary for each IP task category**

Dependent measure: Hand-off-wheel time  
 Probability values less than 0.05 are shown.

Task Category	Source		
	Gender (G)	Presentation Order (O)	GxO
Bot 1o3	0.0003		
Bot 1o6		0.0153	
Bot 1o12			0.0214
LEDC High		0.0045	
LEDC Step			
MGE High			
MGE Low		0.0078	0.0109
PB Directed			
PB 1o5			
RT 1o4S		0.0013	
RT 1o9S			
Telephone 11			
Top AMT			
Top Time			0.0365
Top 1o5			

**Table 68. Analyses of variance summary for each IP task category**

Dependent measure: Average length of glances to the roadway  
 Probability values less than 0.05 are shown.

Task Category	Source		
	Gender (G)	Presentation Order (O)	GxO
Bot 1o3			
Bot 1o6			
Bot 1o12			
LEDC High			
LEDC Step			
MGE High		0.0012	
MGE Low			0.0331
PB Directed			
PB 1o5			
RT 1o4S			
RT 1o9S	0.0247		
Telephone 11			
Top AMT			
Top Time			
Top 1o5			

Table 69. Analyses of variance summary for each IP task category

Dependent measure: Number of glances to IP  
 Probability values less than 0.05 are shown.

Task Category	Source		
	Gender (G)	Presentation Order (O)	GxO
Bot 1o3			
Bot 1o6		0.0090	
Bot 1o12			
LEDC High			
LEDC Step			
MGE High		0.0013	
MGE Low			
PB Directed		0.0284	
PB 1o5			
RT 1o4S		0.0093	
RT 1o9S			
Telephone 11			
Top AMT		0.0448	
Top Time			0.0254
Top 1o5			

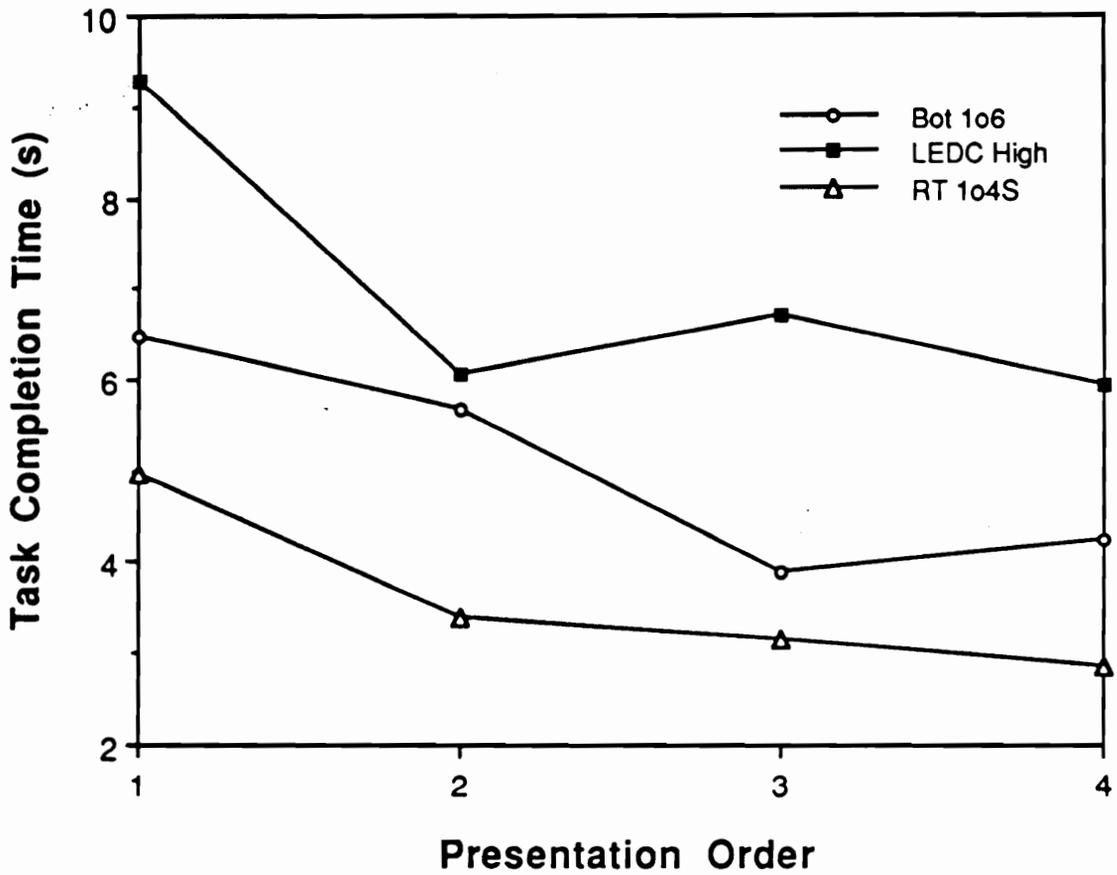


Figure 59. Interaction between IP task category and Presentation Order: Task completion time

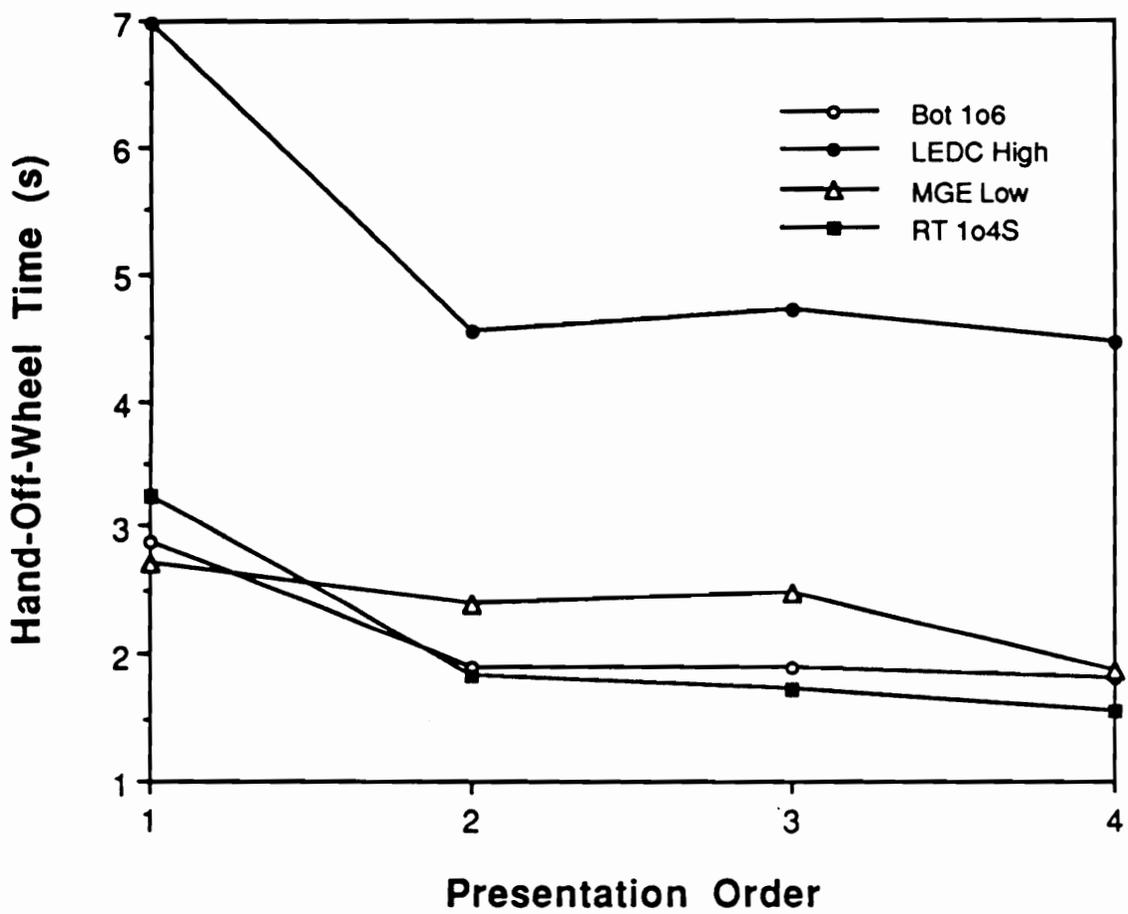


Figure 60. Interaction between IP task category and Presentation Order: Hand-off-wheel time

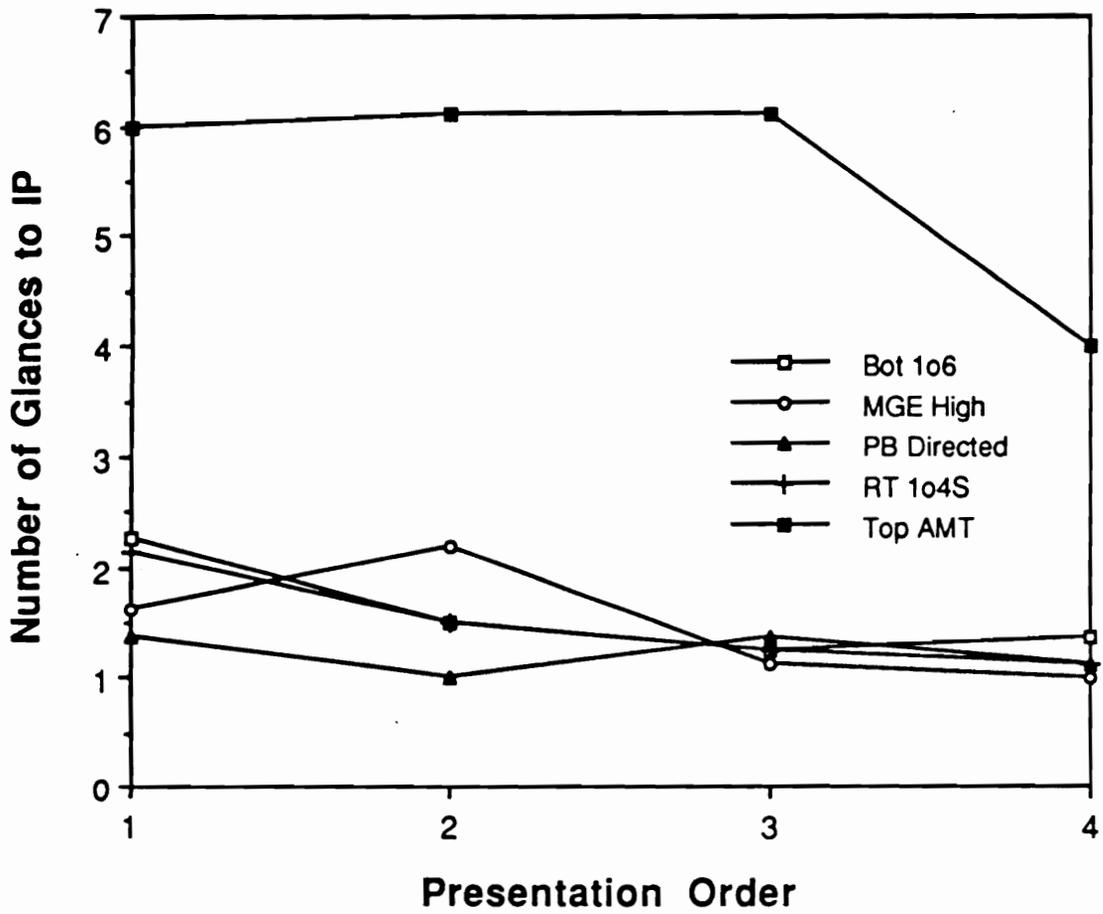


Figure 61. Interaction between IP task category and Presentation Order: Number of glances to IP

There were also significant interactions involving gender. The interaction between gender and task categories in hand-off-wheel time was evidently caused by the significant effect of gender in task category Bot 1o3 (Table 67). The interactions between gender and the presentation order are shown in Figures 62 and 63. It appears that female subjects demonstrated greater improvements over observations than male subjects did. Lastly, the three-way interaction among gender, presentation order, and task category was the result of a significant two-way interaction between the former two factors in task category MGE Low (Table 68 and Figure 64).

### *Discussions (Experiment 3)*

The purpose of this experiment was to investigate the effects of control label ambiguity as a result of abbreviation and of microclutter within a control panel, which was influenced by the number of controls and by the amount of space that labels occupied around the controls. The number of controls i.e., simulated touch panel type, had significant effects on most measures. In particular, task completion time and the number of glances to the touch panel were directly proportional to the number of control buttons (and means were significantly different from one another), and the average length of glances to the touch panel was significantly longer for the multiple button configurations. These results are in agreement with those reported by Rockwell (1983). The greater number of controls within an instrument increased not only the difficulty of the task to search for and locate a target (as reflected by the longer glance to the touch panel), but also the complexity of the task. Visual segmentation (Rockwell, 1983) of the touch panel might have required more steps, or task elements, to scan and examine the greater number of controls, resulting in more glances.

The label abbreviation was also found to have significant effects on task completion time and the number of glances to the controls: the single-line abbreviation, i.e., the shortest labels, was significantly less (over 10%) than the double-line abbreviation and fully spelled labels (there was no significant difference between these two). This difference seems to indicate that the level of micro-

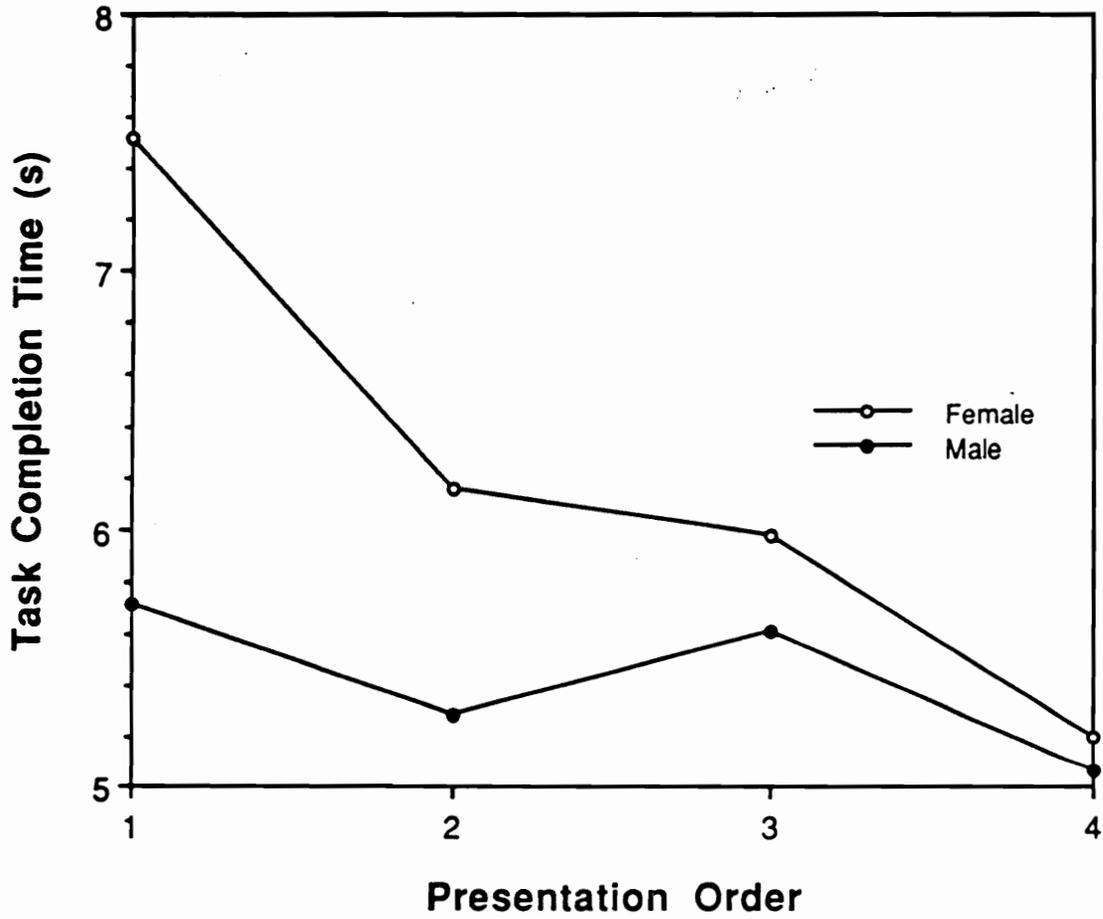


Figure 62. Interaction between Gender and Presentation Order: Task completion time

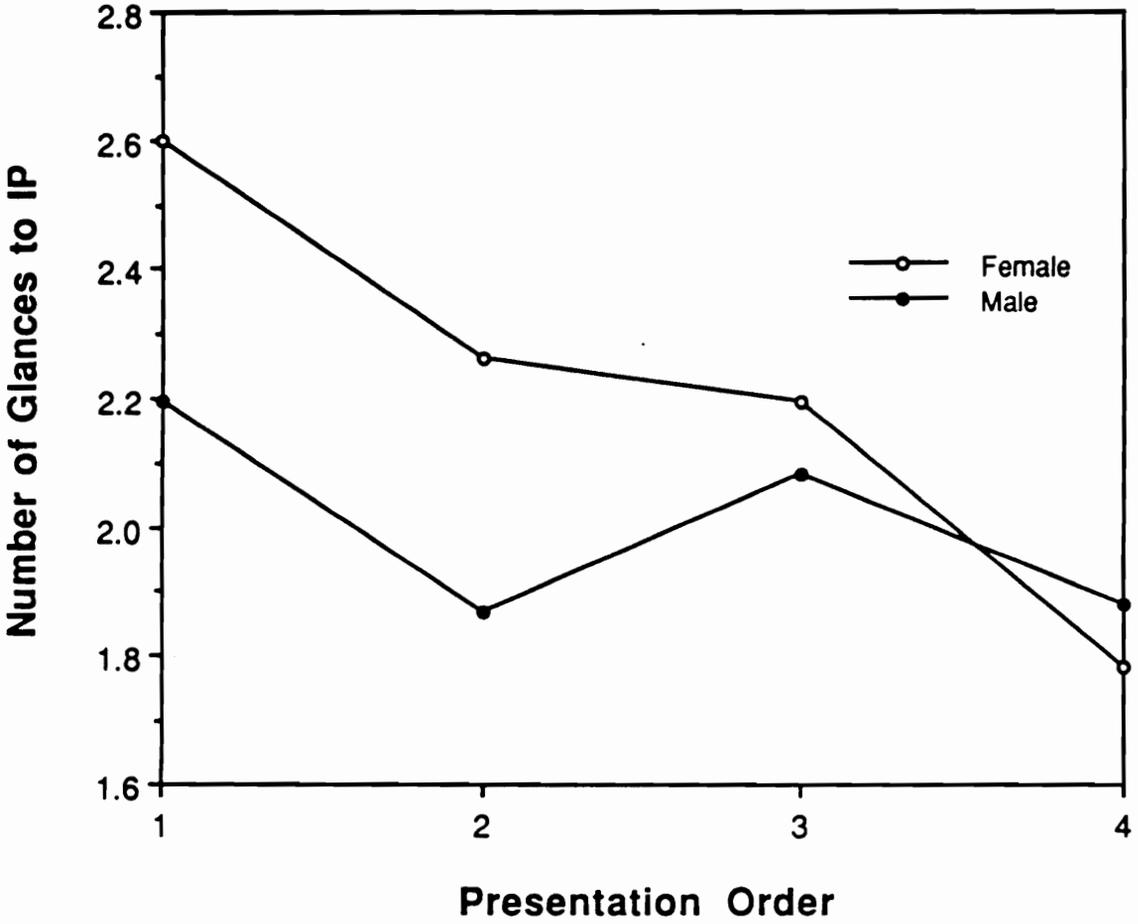


Figure 63. Interaction between Gender and Presentation Order: Number of glances to IP

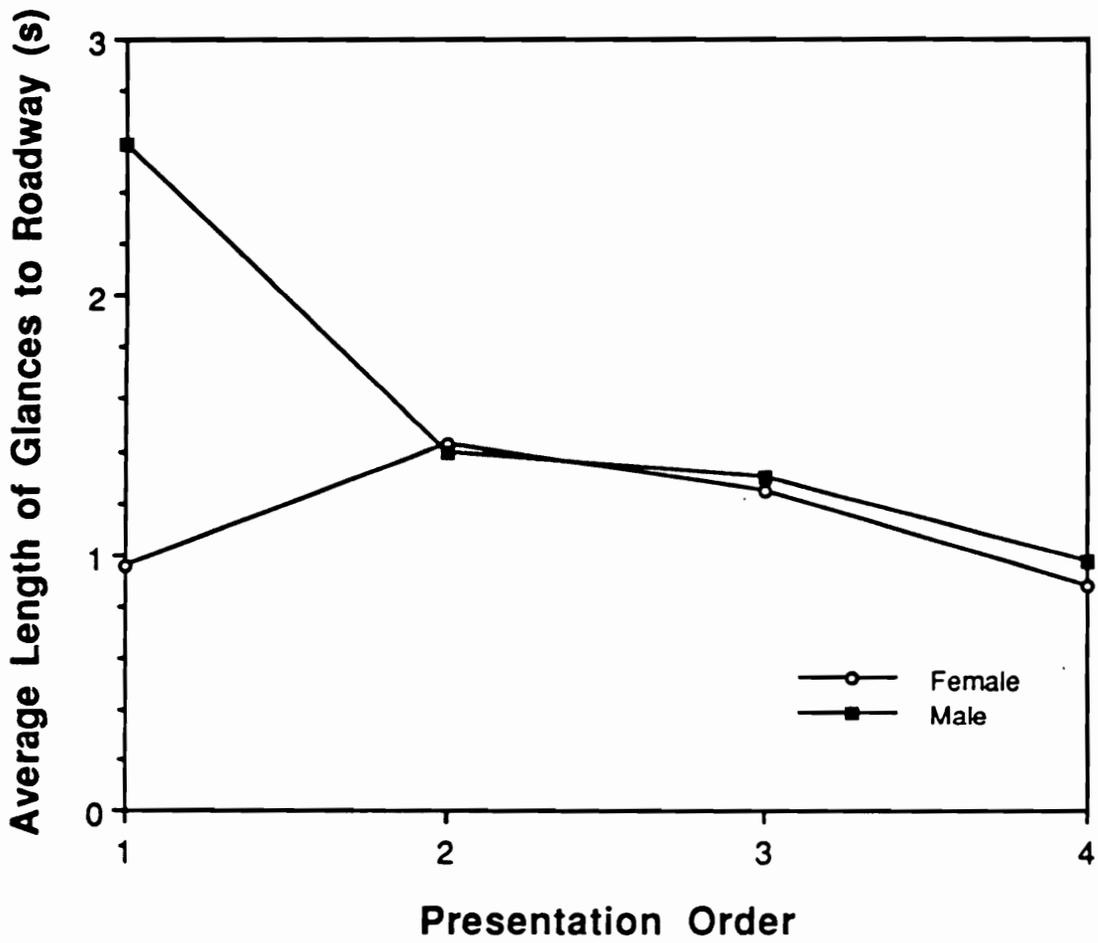


Figure 64. Interaction between Gender and Presentation Order in MGE Low: Average length of glances to the roadway

clutter caused by control labels has a greater influence on task performance than the ambiguity of labels.

The results indicate that well chosen abbreviations of control labels are easier to locate, when a large number of controls are involved, than fully spelled labels which cause no ambiguity. The effect of label ambiguity, of course, diminishes as drivers become familiar with the operation of their own vehicles, and abbreviated labels that make controls distinct among others would be adequate. Therefore, driver task performance is more sensitive to the IP microclutter than to the ambiguity of control labelling.

## Summary

Extensive data on conventional IP tasks were gathered in the controlled conditions of the driving simulator in order to supplement those from the previously reported studies, and some basic issues concerning IP clutter and control labelling were investigated during the series of three experiments. The first experiment in which the level of random crosswind was varied to simulate different driving workload showed that the condition with no crosswind present provided the closest driving condition to that on the road. Although the driving simulator lacks the complex roadside scenery and traffic pattern of actual roadway, the task performance data measured in the simulator are close enough to allow valid examinations of issues involved in IP design.

During the second and third experiments, the effects of IP macro- and micro-clutter were investigated. Both types of IP clutter had significant effects on task completion time and number of glances to IP. Comparisons of the strength of these effects revealed that microclutter had a much greater influence on task performance. While the difference between the minimal macroclutter (single control cell configuration) and the maximum (2 x 3 cell configuration) is just over 50%, the difference between the minimal microclutter (single button) and the maximum (3 x 3 array of buttons) was about 100%. That is, task completion time and number of glances to IP were twice as much in the 3 x 3 panel as in the single button.

Significant effects of label type and abbreviation were also found in these experiments. Time to locate and touch a specific control was almost 10% longer when the controls were randomly labelled with the alphabet than when they were consecutively numbered. Locating controls with single-line abbreviation took a significantly shorter time and required significantly less glances to IP. These results indicate that a well chosen abbreviation that is consistent with driver's expectation is superior to the fully spelled form.

Base-line IP task performance data were also collected under the static simulator condition, in which subjects did not drive the simulator and performed only IP tasks. These data might also be used to estimate the in-car, on-road performance.

## DEVELOPMENT OF EVALUATION PROGRAM

In this phase of the research program, a computer program which evaluates driver IP task performance was developed. The program was written in Pascal on the Apple Macintosh II micro-computer and utilizes the extensive graphics capabilities and user-friendly interface of the Macintosh computer, which allow users with minimal familiarity with the Macintosh to use the program.

The primary objective of this program is to aid automotive IP designers in evaluation of an instrument design on the basis of estimated driver task performance. Users can obtain the estimates (1) empirically from the existing experimental data, (2) by assessing the difficulty, complexity, and manual demand of a given task, or (3) by analyzing the behavioral characteristics of the task elements. This program is also intended to form a sound basis on which to continue and expand research efforts in modelling driver IP task performance.

The program, IPanalyzer, characterizes driver task performance by the following measures:

- Task completion time
- Hand-off-wheel time
- Total glance time to IP
- Number of glances to IP
- Average length of glances to IP
- Average length of glances to the roadway
- Average eye transition times

As discussed earlier, task completion time is one of the more common measures which have been used in studies of IP task performance and is more consistently available. Glance to IP measures are often available, in one form or another, and are appropriate measures of visual attentional demand (VAD). Concurrent manual demand (CMD) is measured in hand-off-wheel time, and concurrent driving workload is normally related to the average length of glances to the roadway.

Average eye transition time, between the roadway and IP, is also useful in quantifying certain IP characteristics. The full complement of these seven measures was, however, not always reported in the previous studies. Therefore, assumptions were made, and best estimates were used when the values were not available.

IPanalyzer also defines four types of figures of merit to serve as composite measures of the seven dependent variables. Visual figure of merit is based on the glance to IP measures and is intended to represent VAD; whereas manual figure of merit is proportional to hand-off-wheel time and represents CMD. Overall figure of merit is a weighted sum of the visual and manual figures of merit, and consequently provides frequency-of-use adjusted figure of merit. These figures of merit offer relative measures of various IP configurations and are useful when considering alternative designs.

Using IPanalyzer, performance measures for a given type of IP tasks (task category) are obtained in several ways. For conventional IP tasks, users can follow the task directory approach and select a task of interest from the list of tasks for which experimental data exist. Users can alternatively specify a task through a hierarchical selection tree of the task characteristics approach. For most conventional IP task categories, IPanalyzer provides the exact values from the existing database.

If no data are available for a task of interest, users can obtain estimated IP task performance through two distinct methods. Under the first estimation method (the task estimate procedure), users assess the difficulty, complexity, and manual demand of an IP task and estimate the average length and number of glances to IP, and hand-off-wheel time, respectively, using benchmark values from the existing data. By selecting values which best represent the task of interest, users can obtain performance estimates.

Under the alternative method (the task analytic procedure), a task of interest is first defined in terms of its task elements through a task analysis. Users then categorize each task element on the basis of its behavioral characteristics and enter the number of each category of task elements. IPanalyzer obtains the performance estimates for each type of task element based on the existing data and then

computes the overall estimates for an entire task by summing the estimates for each task element. This method offers an alternative means to estimate driver IP task performance that is not restricted by the conventional terminology to describe operations and interface. A task to be considered is defined with less interface-specific, broader behavioral descriptions.

All IP task performance estimates are adjusted to take into account the effects of the following external factors:

- Driver age group
- Driver gender
- Concurrent driving workload
- Location of the instrument used by a task
- Factors related to instrument labels

The driver age group and concurrent driving workload have been consistently found to be significant factors in the previously reviewed studies. The gender and instrument location factors also resulted in some, although not significant, differences in Hayes et al. (1988). The effects of label character size and luminance were found to influence the check-reading element of a task by Imbeau (1987). These five independent variables are thus applied to provide more precise estimates of driver IP task performance.

## Program IPanalyzer

### *System requirements*

IPanalyzer was developed in Pascal using an Apple Macintosh II computer, with 2 megabytes of random access memory (RAM), an 80 megabyte hard drive, and an AppleColor high-resolution (640 × 480 pixel) RGB monitor, operating under the System version 6.0.3. This program is compatible with any type of Macintosh computer with a minimum of 1 megabyte of RAM. As the executable file of IPanalyzer is approximately 90 kilobytes in size, use of a hard drive is not required. Use of a smaller size monitor, e.g. a 512 × 342 monitor of Macintosh Plus and SE, is acceptable, although some windows may overlap. Although the present version does not support PostScript page formatting, the print option of IPanalyzer is compatible with any type of printer.

To use IPanalyzer, only a minimal familiarity with Macintosh computers is required. Those with no prior experience with Macintosh computers may wish to familiarize themselves with a tutorial disk "Your Apple Tour of the Macintosh II," or the first chapter of the Macintosh system software user's guide (Apple Computer, Inc., 1988), both of which are provided with a Macintosh computer package.

### *Program requirements*

The program codes were generated and compiled with Symantec THINK Pascal™ version 3.0.1, while resource codes were created with ResEdit version 1.2. An executable application file named IPanalyzer is the only file required to run IPanalyzer. The application IPanalyzer consists of the following ten source files:

1. IPanalyzer.pas
2. LevelOne.pas
3. IPTaskData.pas

4. IPutility.pas
5. IPprinter.pas
6. SwanExtras.pas
7. DialogUnit.pas
8. PrintUnit.pas
9. TextUnit.pas
10. IP Resources

If on-line help is desired, text files with extension HELP should be accessible at the runtime.

Source files 1 through 5 contain the basic functions of IPanalyzer, and the program structure is shown in Figure 65. Source files 6 through 9 contain codes for support routines which make possible the graphic interface typical of Macintosh applications for this program and were adapted from Swan (1987) and extensively modified. Source file 10 is the resource file which contains all window and dialog box templates and other miscellaneous information. All of these files are necessary to compile an executable application file. Those interested in making modifications to IPanalyzer are referred to THINK Pascal™ User manual (Symantec, 1990a) and Resource utility manual (Symantec, 1990b).

### *Using IPanalyzer*

Upon starting IPanalyzer, users will see a menu bar across the top and a status window along the left side of the screen (Figure 66). These items remain on the screen at all times: the menu bar allows users access to various functions of IP analyzer, and the status window displays the results of operations which users perform. If IPanalyzer is running under the MultiFinder multitasking operating system, windows and icons from other applications might appear behind the status window. Since IPanalyzer is compatible with MultiFinder, users can switch between IPanalyzer and other applications at will, provided that the Macintosh system in use has enough RAM to support them. While the interface of IPanalyzer was designed as consistently as applicable with that of a standard

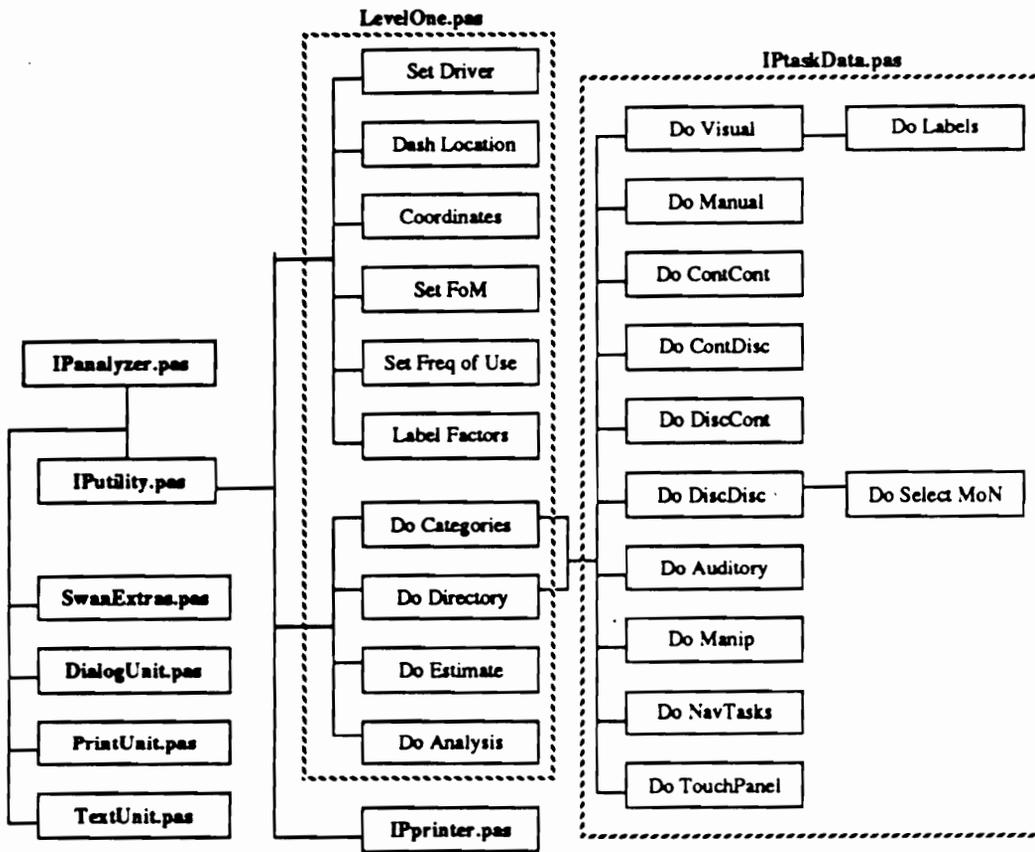


Figure 65. Program structure of IPanalyzer

Macintosh application, the display contents of the status window and menu bar items are explained in detail below.

**Status window** The status window contains 24 fields, as shown in Figure 66. At the very top is the field, which displays the name of an IP task category or a performance estimation procedure, both of which are explained in the following sections. There are two columns of three fields each in the boxed area below the IP task name box, and these fields are used to display any additional parameters that are specific to a function or a routine. In the third boxed area are the current settings of three external factors, of which effects are applied across IP tasks (i.e., driver age group, driver gender, and level of concurrent driving workload). The seven IP task performance measures that have been discussed in the previous sections are displayed in the fourth boxed area. Shown in abbreviated form they are:

1. Task completion time in seconds (Task Time)
2. Hand-off-wheel time in seconds (Hand-Off)
3. Number of glances to IP (Num.IPG)
4. Average length of glances to IP in seconds (Avg.IPG)
5. Total glance time to IP in seconds (Total IPG)
6. Average length of glances to the roadway in seconds (Avg.DRV)
7. Average eye transition time in seconds (AvTrans)

Contained in the boxed area are two columns of seven fields each, which allow two sets of values to be shown simultaneously. There are also two columns of four fields each for the four types of figures of merit in the boxed area below the dependent measure box. They are:

1. Visual figure of merit
2. Manual figure of merit
3. Overall figure of merit
4. Frequency of use adjusted figure of merit

🍏 **File Edit Task Options**

<b>Status</b>	
<b>Task:</b>	
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	
<b>Hand-Off:</b>	
<b>Num.IPG:</b>	
<b>Avg.IPG:</b>	
<b>Total IPG:</b>	
<b>Avg.DRV:</b>	
<b>AuTrans:</b>	
<b>Figure of Merit</b>	
<b>Visual:</b>	
<b>Manual:</b>	
<b>Overall:</b>	
<b>Adjusted:</b>	
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

Figure 66. Menu bar and status window

In the bottom boxed area, the measures of an instrument location, i.e., horizontal and vertical angles off the forward view, are shown.

**Menu bar** Five titles are included in the menu bar of IPanalyzer. From the left they are: (1) Apple menu, (2) File menu, (3) Edit menu, (4), Task menu, and (5) Options menu. Available in Apple menu are the information box which contains information about IPanalyzer, Help command which allows access to the text files containing information about various parts of IPanalyzer, and desktop accessories that are installed in the particular Macintosh system. When the information box is selected, the application heap is compacted to release all purgeable blocks and to minimize heap space fragmentation. When the Help command is selected, either by releasing the mouse button when the command is highlighted or by typing the Command-H shortcut, a standard directory dialog box will appear. The dialog box will show names of any folders, and text files with extension HELP; if the option key is pressed along with the mouse button, the dialog box will instead show any text files. Since no command in the Edit menu is applicable for the current version of IPanalyzer, the menu title is dimmed and no selection can be made.

Three standard commands are currently available in File menu (Command-key shortcuts are shown in parenthesis):

1. Page Setup...
2. Print... (Command-P)
3. Quit (Command-Q)

Page Setup command allows users to define printing features, and further information is available in the printing section (pp. 105 - 107) in Chapter 3 of Macintosh System Software User's Guide, version 6.0 (Apple Computer, Inc., 1988). Print command is available only when an IP task is specified, and it is otherwise dimmed to indicate that it is not available. When the Print command is selected from the menu bar, an exact copy of the status window and its display contents is printed. The status window and its contents can also be printed while inside a routine by typing

the Command-P shortcut. This feature is useful when users wish to have a printed record of the current selection before any change is made. Once the Print command is selected, an appropriate print dialog box will appear to allow users to enter printing parameters for the type of printer that is selected by the Chooser desk accessory (see pp. 127 - 133 in Chapter 5 of Macintosh System Software User's Guide, version 6.0 (Apple Computer, Inc., 1988)). The Quit command terminates the execution of IPanalyzer.

In the Task menu, there are four items (Command-key shortcuts are shown in parenthesis):

1. Directory (Command-D)
2. Characteristics (Command-R)
3. Estimate (Command-E)
4. Analysis (Command-A)

In the Options menu, there are six items:

1. Driver definition
2. Instrument Location
3. Instrument Coordinates
4. Figure of Merit
5. Frequency of Use
6. Label Factors (dimmed when not applicable)

Selecting one of these menu items directs users to different portions of IPanalyzer, which are described in detail in the following sections. While in a routine under one of these menu items, the corresponding menu title will remain highlighted to indicate that the routine is in progress and no other menu item selection can be made.

## Options menu

The Options menu contains dialog boxes that allow users to set the levels of external factors and to set the weighing constants in the computation of figures of merit which are applied globally across IP task measures and estimates. When IPanalyzer is started, each parameter is set to a default value. The value remains the same until the appropriate Options item is selected and a new value is entered. These parameters can be changed at any point, however, users must exit the Task menu routine before an Options item can be selected. Once a new setting is selected or a new value is entered, the dependent measures and figures of merit are immediately recomputed to reflect the change, and users can try as many settings or values as they wish while in any of the Options menu routine.

The effects of the external factors, i.e., driver age group and gender, concurrent driving workload, instrument location in the dashboard, and factors related to instrument labels, were determined empirically from the previous studies. Appropriate multiplicative or additive factors were calculated and placed in the computation algorithm, which adjusts the dependent measures as the parameters are set. One important assumption which was made in developing these routines was that no significant interaction exists between IP task category and these external factors. That is, the effect of each factor is assumed to be independent of IP tasks and uniform across the IP task performance measures and estimates.

The only driver IP task performance study that has reported testing for interactions involving IP task category is the driving simulator experiments that were described in the preceding chapter (also Kurokawa et al., 1989). In these experiments, significant interactions are found between IP task category and random crosswind (Experiment 1) in task completion time ( $p = 0.0375$ ) and number of glances to IP ( $p = 0.0001$ ), between IP task category and simulated road type (Experiment 2) in task completion time ( $p = 0.0012$ ), hand-off-wheel time ( $p = 0.0001$ ), and number of glances to IP ( $p = 0.0001$ ), and between IP task category and gender in average length of glances to the roadway ( $p = 0.0408$ , Experiment 2), and in hand-off-wheel time ( $p = 0.0367$ , Experiment 3).

Assuming that the strength of random crosswind and type of simulated road type influence the concurrent driving workload, the only dependent measure that was consistently affected by the interaction involving IP task category was the number of glances to the IP. Potential benefits of including this interaction and concurrent driving workload were weighed against the cost of its inclusion. While this finding is in no way trivial, it was decided not to include this interaction in the computation algorithm because (1) the precise relationship between concurrent driving workload and these experimental variables is not known, (2) the IP task category interaction can only be applied to the tasks with existing data and not to the performance estimation procedures, and (3) the additional constants and programming complexity necessary to accommodate this interaction were not justified.

Having decided not to include interactions involving IP task category, means across IP task categories were used to obtain correction factors. Each correction factor is explained in the following sections.

#### *Driver definition*

Driver age group and gender, and the level of concurrent driving workload are entered in the driver definition dialog box (Figure 67). Multiplicative factors were calculated from means for each driver group and level of driving workload and incorporated in the computation algorithm.

**Driver gender** Most studies have not reported significant effects of gender. However, adjustment factors for gender have been included to provide a greater precision in performance estimates (Table 70).

**Driver age group** Overall mean dependent measures and means for each age group from three IP task performance studies are shown in Table 71. Approximate ranges in years of age are (1) between 18 and 30 for the younger group, (2) between 30 and 50 for the middle group, and (3) 50 and up for the older group. As the driver age group has been found to be a significant factor and is also

<b>Age</b>	<b>Gender</b>	<b>Workload</b>
<input type="radio"/> 18 - 24	<input type="radio"/> Male	<input type="radio"/> Low
<input type="radio"/> 25 - 49	<input type="radio"/> Female	<input type="radio"/> Medium
<input type="radio"/> 50 +	<input checked="" type="radio"/> Both Genders	<input type="radio"/> High
<input checked="" type="radio"/> All Ages		<input checked="" type="radio"/> All Levels
<input type="button" value="OK"/>		

Figure 67. Driver definition dialog box

**Table 70. Mean dependent measures for each gender (Hayes et al., 1988)**

<b>Gender</b>	<b>Overall</b>	<b>Male</b>	<b>Female</b>
Task completion time (s)	4.936	4.474	5.398
Hand-off-wheel time (s)	3.154	2.900	3.408
Number of glances to IP	2.346	2.034	2.658
Av. glance to IP (s)	1.177	1.262	1.092
Total glance to IP (s)	2.658	2.488	2.828
Av. glance to roadway (s)	0.676	0.678	0.674
Av. transition time (s)	0.109	0.110	0.108

Sources: Hayes et al. (1988)

of increasing interest to automotive designers, the data were categorized into these three general age groups.

**Concurrent driving workload** The effect of concurrent driving workload was found to be significant for all dependent measures in Hayes et al. (1988). In their study, the high level was characterized as “involving high traffic density or unanticipated events requiring frequent monitoring, extreme curvature, or minimal forward view.” The medium level involved “moderate traffic, moderate road curvature, or substantial up or down grade.” Finally, “low traffic density, straight and level roads, and no unusual events during task execution” were considered to be the low driving workload condition. Means for each level of concurrent driving workload are shown in Table 72.

Although Hayes et al. (1988) did not find a significant interaction between the driver age group and concurrent driving workload, means for each combination between age group and workload level were also computed (Table 71). For the purpose of providing greater precision, correction factors for each combination were determined from these means and incorporated in the computation algorithm.

#### *Instrument location*

In Hayes et al. (1988), the auxiliary instrument panel (Figure 9), containing a variety of instruments, was mounted in four different positions during their data collection sessions. One of the instruments on the auxiliary IP, a Pontiac pushbutton control center, was also mounted on the steering wheel hub, thus providing the fifth position for this particular instrument. Linear regression analyses were performed using horizontal and vertical angles off the driver’s forward view as regressors, and the results are shown in Table 73. These independent variables appear to make some difference in task completion and hand-off-wheel times, average length of glances to IP, total glance to IP, and average transition time. Intuitively, the farther away from the forward view the instrument is located, the longer the transition time eyes require to move to and from the instrument, the longer the eyes take to accommodate resulting in the longer glances and the longer the total glance time

Table 71. Mean dependent measures for each age group

Age group	Overall			Younger		
Task completion time (s)	9.685	5.000	4.936	7.620	4.320	3.465
Hand-off-wheel time (s)	n.a.	n.a.	3.154	n.a.	n.a.	2.451
Number of glances to IP	5.260	n.a.	2.346	4.250	n.a.	1.833
Av. glance to IP (s)	1.120	1.065	1.177	1.000	1.290	1.037
Total glance to IP (s)	n.a.	3.103	2.658	n.a.	1.000	1.813
Av. glance to roadway (s)	2.885	n.a.	0.676	3.080	n.a.	0.644
Av. transition time (s)	n.a.	n.a.	0.109	n.a.	n.a.	0.102
Sources	1	2	3	1	2	3
1 Monty (1984)						
2 Dingus (1987)						
3 Hayes et al. (1988)						
Age group	Middle			Older		
Task completion time (s)	4.835	4.911	11.750	6.010	6.428	
Hand-off-wheel time (s)	n.a.	3.208	n.a.	n.a.	3.801	
Number of glances to IP	n.a.	2.326	6.270	n.a.	2.878	
Av. glance to IP (s)	2.830	1.234	1.240	1.290	1.259	
Total glance to IP (s)	0.985	2.685	n.a.	4.120	3.474	
Av. glance to roadway (s)	n.a.	0.666	2.690	n.a.	0.717	
Av. transition time (s)	n.a.	0.100	n.a.	n.a.	0.124	
Sources	2	3	1	2	3	
1 Monty (1984)						
2 Dingus (1987)						
3 Hayes et al. (1988)						

**Table 72. Mean dependent measures for workload levels (Hayes et al., 1988)**

Age group	Overall			Younger		
	Concurrent Driving W/L	Low	Medium	High	Low	Medium
Task completion time (s)	4.754	5.254	5.297	3.152	3.871	3.952
Hand-off-wheel time (s)	3.039	3.399	3.175	2.256	2.727	2.668
Number of glances to IP	2.295	2.468	2.306	1.705	2.044	1.867
Av. glance to IP (s)	1.197	1.139	1.149	1.038	1.025	1.077
Total glance to IP (s)	2.655	2.702	2.489	1.697	2.018	1.793
Av. glance to roadway (s)	0.633	0.727	0.861	0.618	0.659	0.757
Av. transition time (s)	0.110	0.107	0.104	0.101	0.104	0.104

Sources: Hayes et al. (1988)

Age group	Middle			Older		
	Concurrent Driving W/L	Low	Medium	High	Low	Medium
Task completion time (s)	4.555	5.535	5.319	6.191	6.848	8.326
Hand-off-wheel time (s)	2.958	3.692	3.289	3.729	3.969	4.127
Number of glances to IP	2.221	2.530	2.357	2.825	2.986	3.217
Av. glance to IP (s)	1.258	1.199	1.180	1.271	1.223	1.258
Total glance to IP (s)	2.632	2.803	2.632	3.434	3.541	3.820
Av. glance to roadway (s)	0.591	0.775	0.848	0.681	0.763	1.120
Av. transition time (s)	0.103	0.097	0.097	0.125	0.125	0.118

Sources: Hayes et al. (1988)

to the IP. The hand-off-wheel time also increases as the instrument location increases from the initial hand position on the steering wheel. As the result of these increases, task completion time also increases somewhat.

The default values of horizontal and vertical angles off the forward view which are set when IPanalyzer is started are the coordinates of the center of the auxiliary instrument panel in the lower angled position of Hayes et al. (1988), which was also used in the driving simulator experiments (also Kurokawa et al., 1989). An instrument location of interest is entered in two different forms, and the input values are then converted to horizontal and vertical angles off the forward view for adjusting measures.

If three-dimensional coordinates of the driver's eye position and instrument position are known, the instrument coordinates Options routine should be used (Figure 68). In the automotive design convention, the x-axis is along the longitudinal axis of vehicle, the y-axis along the lateral, or transverse, and the z-axis along the vertical. Upon selecting this Options routine, the eye coordinates are set to the origin (0, 0, 0) and the instrument coordinates relative to the origin. Users can enter new sets of coordinates relative to any point in space (as long as both eye and instrument positions are determined with the same coordinates), and new horizontal and vertical angles off the forward view are calculated and displayed in the status window.

Alternatively, users can enter the two dimensional location of an instrument in the dashboard plane by using the instrument location Options routine (Figure 69). The window contains a graphic representation of a typical dashboard, and users can specify an instrument location in the dashboard by moving the cursor arrow to the desired location in the window and clicking the mouse button. A shaded box will then appear to indicate the dashboard position that has been selected, and new horizontal and vertical angles off the forward view are calculated and displayed. To make selection of a position easier, the corresponding y and z coordinates are also displayed in the additional parameter area of the status window. (In this routine, the distance between driver's eyes and dashboard, along the x-axis, is fixed at 680 millimeters (26¾ inches).

**Table 73. Auxiliary IP locations and regression results**

<b>Auxiliary IP Position</b>	<b>Dashboard</b>	<b>High</b>	<b>High Angled</b>	<b>Low</b>	<b>Low Angled</b>
<b>Between line of sight and center of panel</b>					
Horizontal distance (mm)	0	428.62	444.50	447.68	434.98
Vertical distance (mm)	304.80	171.45	171.45	425.45	425.45
Horizontal angle	0	35.23	37.12	36.69	36.56
Vertical angle	24.16	13.34	13.46	34.60	35.63
Distance between eye and center of panel (mm)	679.45	742.95	736.60	749.30	730.25
Angle between vehicle longitudinal axis and panel stand		0	23	0	23
Panel tip back angle		0	0	62	62

Sources: Hayes et al. (1988)

**Regression results**

Task completion time = 3.894 + 0.0159 \* Angle(Horizontal) + 0.0280 \* Angle(Vertical)

Hand-off-wheel time = 1.786 + 0.0272 \* Angle(Horizontal) + 0.0289 \* Angle(Vertical)

Average glance to IP = 1.097 + 0.00496 \* Angle(Horizontal) + 0.00223 \* Angle(Vertical)

Angle(Vertical)

Total glance to IP = 2.293 + 0.0105 \* Angle(Horizontal) + 0.00473 \* Angle(Vertical)

Average eye transition = 0.0845 + 0.000512 \* Angle(Horizontal) + 0.000444 \* Angle(Vertical)

Angle(Vertical)

**Instrument Coordinates**

	<b>X (mm)</b>	<b>Y (mm)</b>	<b>Z (mm)</b>
<b>Eye Position</b>	0	0	0
<b>Instrument</b>	679.45	434.98	425.45

**Ok**

Figure 68. Instrument location in coordinates entry dialog box

File Edit Task Options

Status	
Task:	Speedometer
Y (Hor)/mm	342.00
Z(Vert)/mm	141.40
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	2.71
Hand-Off:	0.76
Num.IP6:	1.21
Avg.IP6:	0.91
Total IP6:	1.21
Avg.DRU:	0.50
AuTrans:	0.09
Figure of Merit	
Visual:	12.35
Manual:	8.32
Overall:	11.14
Adjusted:	11.14
Angles off Boresight	
Horizontal:	26.72
Vertical:	11.76

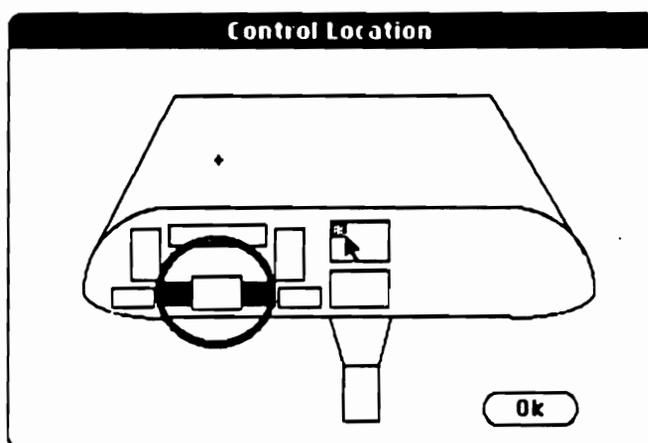


Figure 69. Instrument location in dashboard entry window

If an IP task is already selected when either of these Options routines is selected, the dependent measures and figures of merit are also automatically updated.

### *Control label factors*

As reviewed in the previous chapter, Imbeau (1987) reported significant effects of character luminance and size and significant interaction between these factors on the word reading task in the simulator driving environment. Since many IP tasks involve identification of control labels, it was decided to include these two label related independent variables as another set of external factors. This routine is activated only when an IP task that includes control labels is selected. Users can then enter the control character size and luminance, as well as the driver's reliance on labels to perform the task of interest, through this routine's dialog box (Figure 70).

**Character luminance and size** Imbeau (1987) reported the significant effect of character size on response time and total glance time (Figure 7, Table 74). Means indicate that these measures leveled out for character sizes larger than 17 arc minutes; these measures, however, increased significantly for smaller sizes. In addition, as shown in Figure 71, for the smaller character sizes, the character luminance level made a significant difference in response time.

The default character size in this Options menu routine was set to 17 arc minutes. Regression analyses were then performed to fit the values above and below this reference character size. Total glance time was deemed to remain constant above 17 arc minutes, and a correction factor for the smaller size was determined as:

$$2.976 - 0.697 \ln(\text{character size in arc minutes}).$$

**Label Factors**

**Label Character Size**  
 arc minutes @ eye

**Label luminance**  
 High  
 Low

**Degree of driver reliance on labels**  
 1.0 Total Reliance  
  
  
 0.5 Moderate  
  
  
 0.0 No reliance

Figure 70. Control label factor entry dialog box

**Table 74. Check-reading task data (Imbeau, 1987)**

<b>Character size (arc minutes)</b>	<b>7</b>	<b>11</b>	<b>17</b>	<b>25</b>
<b>Task completion time (s)</b>	<b>see below</b>		<b>1.43</b>	<b>1.36</b>
<b>Hand-off-wheel time (s)</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>
<b>Number of glances to IP</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>
<b>Av. glance to IP (s)</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>
<b>Total glance to IP (s)</b>	<b>1.39</b>	<b>0.88</b>	<b>0.73</b>	<b>0.73</b>
<b>Av. glance to roadway (s)</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>
<b>Av. transition time (s)</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>	<b>n.a.</b>

**Response Time (s) by Character color**

<b>Character size (arc minutes)</b>	<b>7</b>	<b>7</b>	<b>11</b>	<b>11</b>
<b>Character Luminance</b>	<b>Low</b>	<b>High</b>	<b>Low</b>	<b>High</b>
<b>Means across color</b>	<b>4.14</b>	<b>3.00</b>	<b>2.06</b>	<b>1.76</b>
<b>Blue Green</b>	<b>4.26</b>	<b>2.93</b>	<b>2.08</b>	<b>1.90</b>
<b>Green Corvette</b>	<b>4.87</b>	<b>3.11</b>	<b>2.35</b>	<b>1.94</b>
<b>Ochre</b>	<b>4.17</b>	<b>2.98</b>	<b>2.17</b>	<b>1.76</b>
<b>Light Blue</b>	<b>4.64</b>	<b>3.29</b>	<b>2.03</b>	<b>1.83</b>
<b>Image Red</b>	<b>4.10</b>	<b>3.07</b>	<b>2.10</b>	<b>1.85</b>
<b>Warm Red</b>	<b>3.56</b>	<b>3.02</b>	<b>1.76</b>	<b>1.58</b>
<b>White</b>	<b>3.47</b>	<b>2.96</b>	<b>1.94</b>	<b>1.65</b>
<b>Amber</b>	<b>4.03</b>	<b>2.60</b>	<b>2.03</b>	<b>1.58</b>

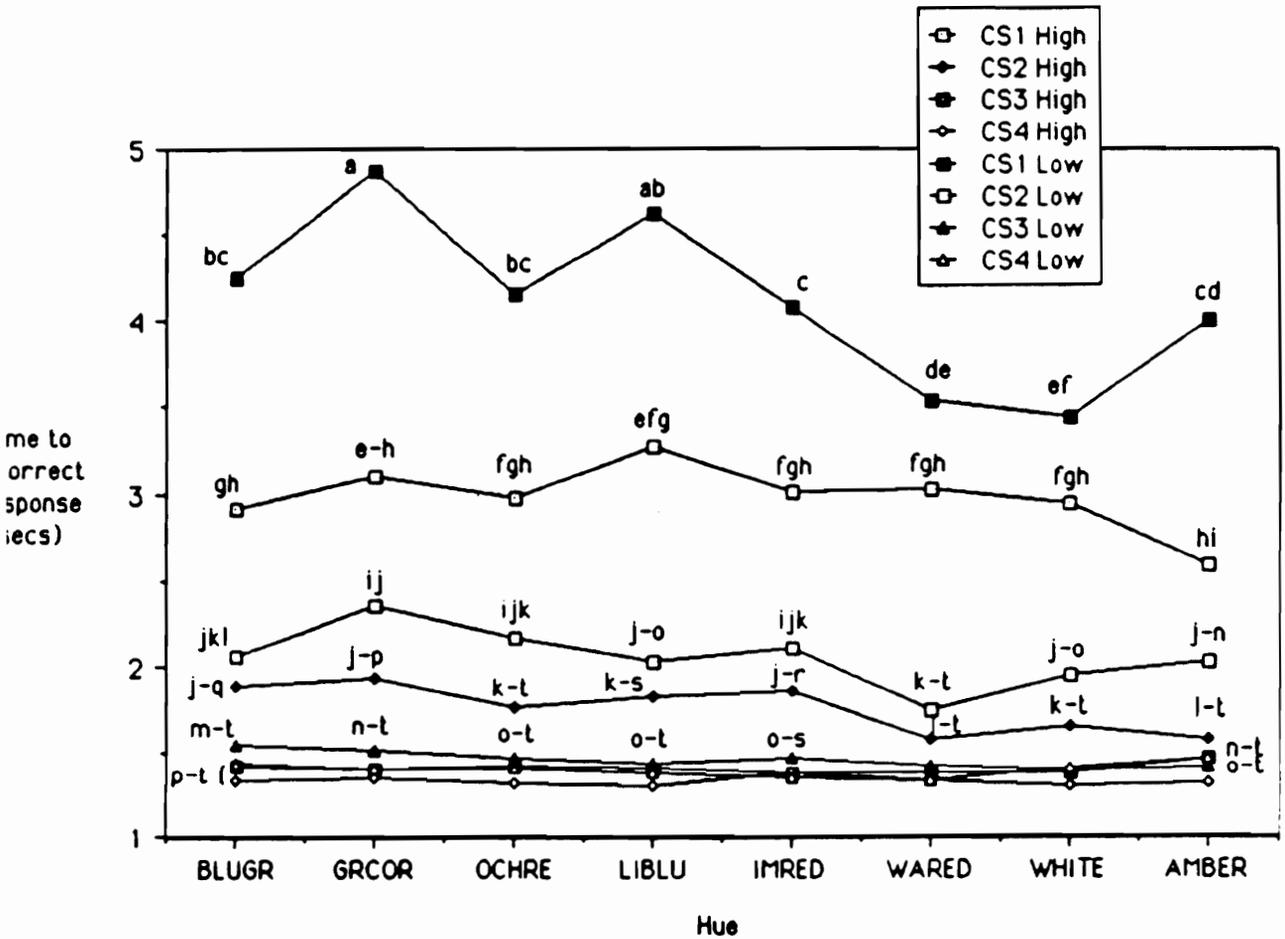


Figure 71. Character color x luminance x size interaction (Imbeau, 1987)

This correction factor is set to 1 at 17 arc minutes, and a progressively larger value is obtained for smaller character sizes. Similarly for the response time, the correction factors are:

$$4.356 - 1.185 \ln(\text{character size}),$$

for character size larger than 17 arc minutes,

$$3.475 - 0.874 \ln(\text{character size}),$$

for character size less than 17 arc minutes and at high luminance level, and

$$5.237 - 1.496 \ln(\text{character size}),$$

for character size less than 17 arc minutes and at low luminance level.

After the character size and luminance level are entered, the adjustment algorithm will multiply task completion time, average length of glances to IP, and total glance to IP with these correction factors to account for these factors related to control labels.

**Driver reliance on label** This factor was added to the previous two label factors because the importance of control labels varies for different tasks and is perhaps different among drivers depending on their familiarity with the instrument. (That is, one might become used to a certain control to the point that s/he can operate it without checking its label.) This factor then adjusts the correction factors for character luminance and size. For instance, if a driver is new to a vehicle and relies heavily on labels to locate instruments, the correction factors should have a full effect. On the other hand, an experienced driver may not need to look to activate a control. The driver's reliance on labels should then be none and the correction factors are irrelevant.

### *Figure of merit*

Figures of merit were formulated to provide a composite measure of driver IP task performance so that alternative designs can be compared under a set of consistent criteria. Two types of figures of merit are first computed to represent visual attentional demand (VAD) and concurrent manual demand (CMD). A weighted sum of these figures of merit provide the overall figure of merit, which

in turn is adjusted for frequency of use for the adjusted figure of merit. These figures of merit offer relative ratings of various IP task designs, as they are defined to be proportional to the level of driver demand, i.e., the greater the figure of merit value, the higher the demand on drivers (and hence a smaller figure of merit value is more desirable).

The visual figure of merit consists of two components:

$$C_1 = 40 (\text{Avg.IPG})^2,$$

where Avg.IPG is the average length of glances to IP in seconds, and

$$C_2 = 3 (\text{Num.IPG})^{3/2},$$

where Num.IPG is the number of glances to IP.

As discussed in the chapter describing the driving simulator experiments, the length of glances to the IP is considered to be proportional to the level of difficulty of the task element in extracting information visually, and thus the average length reflects the average difficulty of all task elements, i.e., a whole task. Since this dependent variable is a very important measure of one aspect of visual attentional demand (VAD), it is squared to assign a heavy weight in the visual figure of merit.

The number of glances to IP, which seems to be related to the number of task elements and is thus considered to reflect the overall complexity of a whole task. While still important, it is perhaps a less critical factor in influencing the visual figure of merit than the average length of glances to IP. Hence, this dependent variable is raised to the 2/3 power to assign somewhat less weight at larger values.

For both dependent variables, the coefficients are determined such that each component value reaches 100 at the overall mean plus two times the standard deviation (these values are computed from the Hayes et al. (1988) data). The intention is to cover 97% (by using  $\pm 2$  s.d.) of data points in a scale of 0 to 100.

These components are then summed according to the following formula:

$$(\text{Visual FoM}) = \alpha C_1 + (1 - \alpha) C_2,$$

where  $\alpha$  is a weighting coefficient between 0 and 1. The default value of  $\alpha$  is 0.5, i.e., equal weights for the two components.

The manual figure of merit, unlike the visual figure of merit components, is linearly related to hand-off-wheel time. Since the concurrent manual demand (CMD), by definition, does not require complete allocation of a driver resource, in this case driver's hands, CMD is considered not as critical as VMD. The scaling coefficient for the manual figure of merit is also set to reach 100 at the overall mean plus two times the standard deviation.

$$(\text{Manual FoM}) = 11 (\text{Hand-off-wheel time})$$

The overall figure of merit is computed by summing the visual and manual figures of merit with another weighting coefficient,  $\beta$ .

$$(\text{Overall FoM}) = \beta (\text{Visual FoM}) + (1 - \beta) (\text{Manual FoM})$$

The default value of  $\beta$  is 0.7, which gives approximately twice the importance on VAD as CMD (appropriate considering the primarily visual nature of driving). These weighting coefficients can be changed by selecting the figure of merit Options routine (Figure 72). Users should be reminded that both coefficients must be set between 0 and 1.

Finally, the adjusted figure of merit is obtained by multiplying the overall figure of merit with a frequency of use coefficient. The adjusted figure of merit is intended to take into account the fact that some IP tasks are performed more often than others. It is useful then to compare the figures of merit for instruments with different frequencies of use. If one instrument is rarely used while driving, a high figure of merit value might be acceptable, as Dingus (1987) concluded about the high VAD of a power mirror adjustment task.

**Figure of Merit Parameters**

$\alpha$  - Weighting of C1 relative to C2:

$\beta$  - Weighting of UFM relative to MFM:

Figure 72. Figure of merit coefficient entry dialog box

The frequency of use is entered in the frequency of use Option menu routine (Figure 73) as the number of times per hour that a task of interest is performed in a normal driving condition. A multiplicative factor is obtained by dividing the number by 10, and the routine computes the frequency of use adjusted figure of merit.

$$(\text{Adjusted FoM}) = (\text{Overall FoM}) \times n / 10,$$

where, n is the number of times per hour the task is performed.

By transforming a group of dependent measures into a single number, these figures of merit make a comparative evaluation of various IP tasks easier. While theoreticians might argue against such an overly simplified approach, it is a practical solution to interpreting the complex set of performance measures.

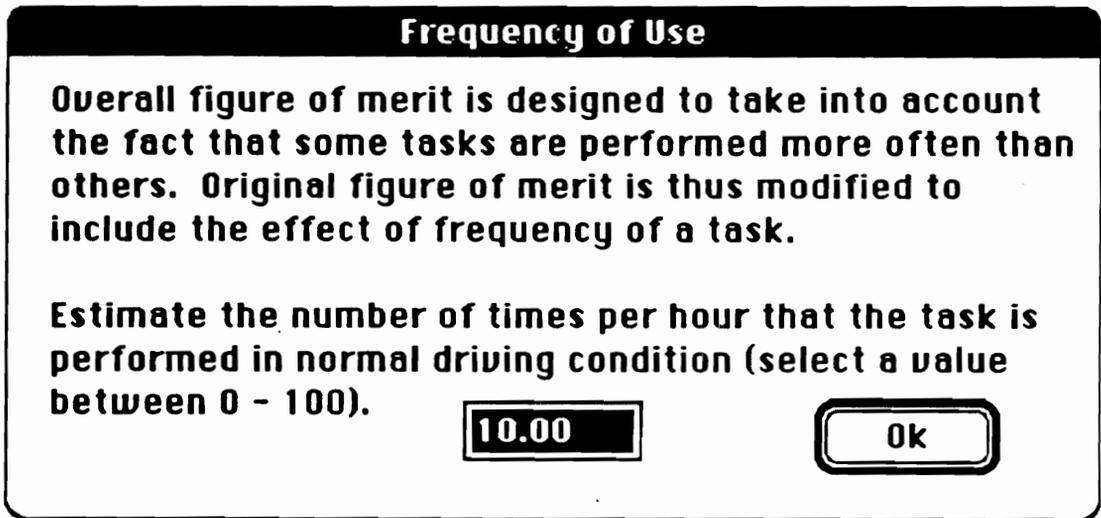


Figure 73. Frequency of use entry dialog box

## Empirical model

This portion of IPanalyzer is based on the available data on driver IP task performance. To be of practical value, this model should not only retrieve values for a particular configuration and conditions of the existing data, but also provide reasonable estimates for other conditions which might be of interest to users. Specifically, the following steps were taken to compile this model:

1. Catalogue all IP tasks for which (most of) the relevant performance data are available
2. Categorize each task by the nature of the task, e.g., the primary mode of operation, the type of feedback, cognitive demands, types of control/display involved, and other interface characteristics
3. Examine, and reanalyze if original data sets are available, the relevant performance measures. As the data are not expected to be available in all variables and conditions, certain assumptions were made in interpreting and adjusting the data.
4. All usable data for each task were compiled as a subroutine in IPanalyzer to function as a computerized data base entry (this modular construction makes a future expansion and inclusion of additional data simple). When a task involved variables, an appropriate formula was created to interpolate values for which no data are available.

In the empirical model, there are two ways to specify an IP task of interest:

1. (by) Directory (Command-D)
2. (by interface) Characteristics (Command-R)

When the Directory Task menu command is selected, the first of two dialog boxes (Figures 75 and 76) will appear on the screen. In the directory dialog boxes, IP tasks with existing data are listed under interface characteristics categories (which are discussed later). Users can move between the

two dialog boxes either by clicking the next / previous button or by pressing a carriage return or enter key. Once an IP task of interest is found in a dialog box, users should bring the cursor arrow to the radio button (i.e., a small circle that, when selected or “punched out”, has a black dot inside) next to the title of the category which contains an IP task of interest and click the mouse button. A new dialog box which contains information about the category and a complete list of IP tasks under the category will then appear. Users can select the specific task, and in most cases the empirically determined performance measures for the requested IP task are displayed in the status window after this selection. After exiting the data retrieval routine that provided the measures, users will be back in the Directory dialog box and able to make further selections.

Alternatively, users can follow the hierarchical selection tree of the by-interface-characteristics approach. When the Characteristics Task menu command is selected, users will see the dialog box which contains the list of interface characteristics under which all IP tasks with existing data are categorized (Figure 74). If users wish to examine IP tasks which share the same interface characteristics, this approach allows a faster access to the category of interest because of its single screen format. A selection is made by moving the cursor arrow to the radio button next to the category of choice and clicking the mouse button. A new dialog box which contains information about the category and a complete list of IP tasks under the category will appear in front of the Characteristics dialog box. Users should then select an IP task of interest and the empirically determined values are displayed in the status window. As in the previous approach, once the data retrieval routine is exited, users will be back in the Characteristics dialog box and able to make further selections.

When selecting either approach in the empirical model, all Options menu parameters remain unchanged from the most recent settings. In addition, the IP task performance measures from the previous selection are overwritten only when the next IP task is selected in one of the data retrieval routines. Hence, if users wish to change the Options menu parameters, after selecting an IP task of interest, users need to exit the data retrieval routine and the top level routine, i.e., the Characteristics or Directory dialog box, and then to proceed to the Options menu. If a printed copy of the selection is desired before any changes are made, users can choose the Print command either

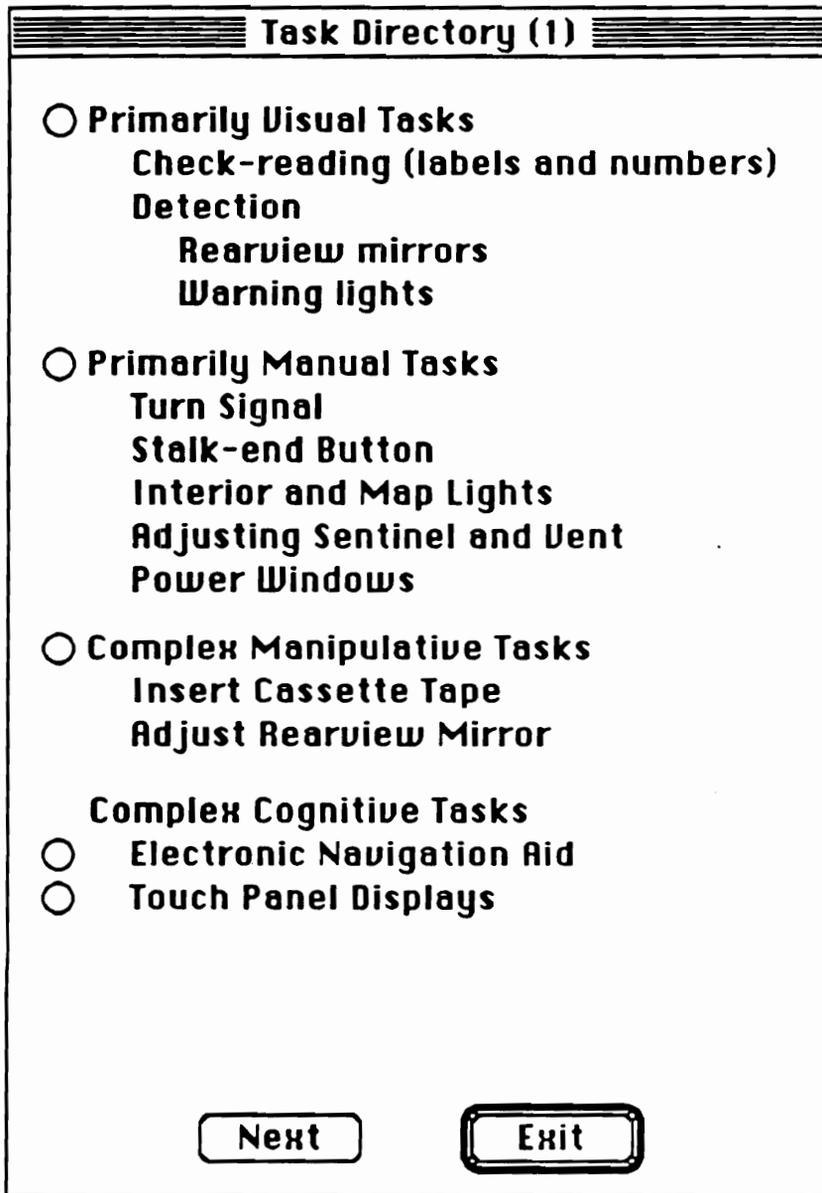


Figure 74. Task directory dialog box (1)

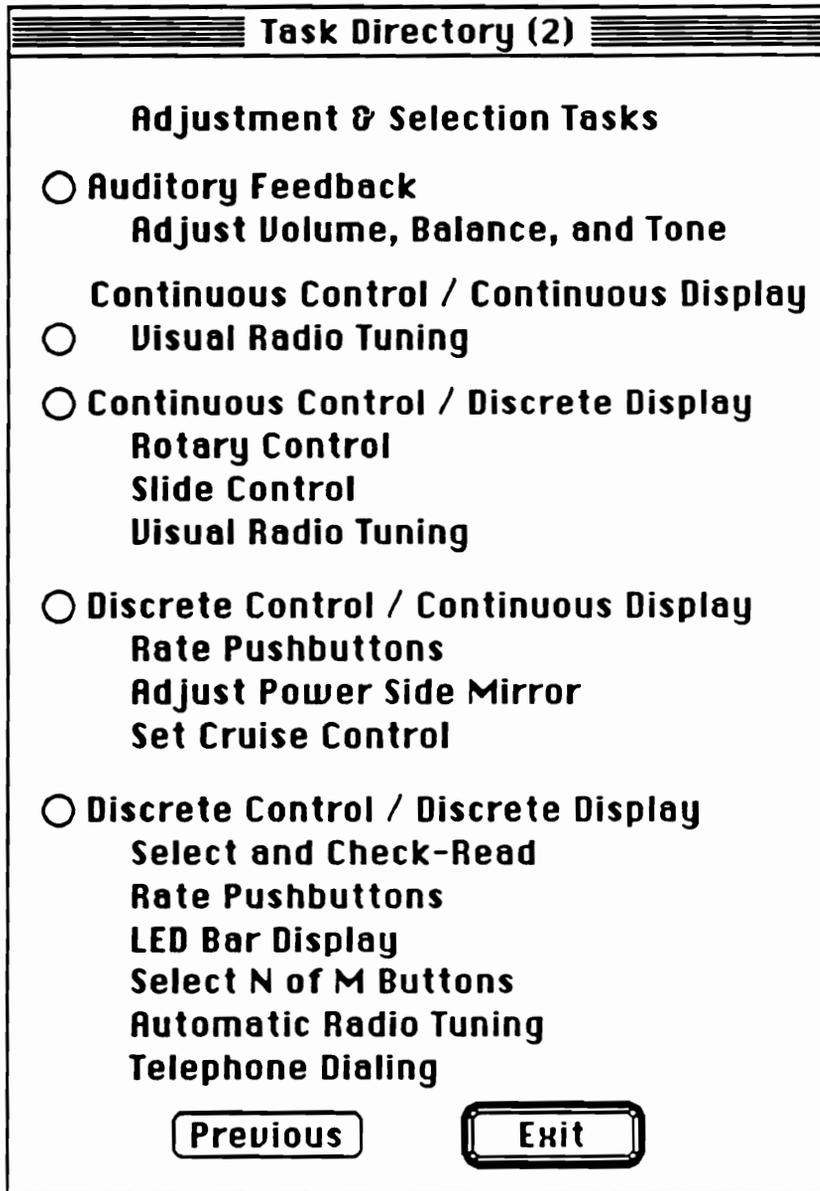


Figure 75. Task directory dialog box (2)

**Task Categories**

- Visual**
- Manual**
- Adjustment & Selection**
  - Continuous control / Continuous display**
  - Continuous control / Discrete display**
  - Discrete control / Continuous display**
  - Discrete control / Discrete display**
  - Auditory feedback**
- Complex Manipulative**
- Complex Cognitive**
  - Electronic navigation aid**
  - Touch panel display**

**Exit**

Figure 76. Task characteristics dialog box

from the menu or by typing Command-P. The latter command is available whether users are still inside a routine or outside the top level routine, i.e., no menu title is highlighted.

The following are the descriptions of each interface characteristics category and of all IP tasks under the category. Each section is also accompanied by figure(s) of the dialog box(es) associated with the relevant data retrieval routine and table(s) which contains overall means of each IP task under the category. (The table also lists the reference source of the data.)

### *1. Primarily visual tasks*

The IP tasks under this category require only that drivers direct eyes to a target area and retrieve information. Theoretically, no CMD exists in the operation of these tasks; the data (Table 75), however, indicate that some drivers removed a hand from the steering wheel during the operation of a task. As shown in the dialog box for this category (Figure 77), the IP tasks under this category are divided into two groups.

**1.1. Check-reading** This subcategory refers to IP tasks for which target information is always present. If the first entry, labels, is selected, users will find another dialog box (Figure 78) appearing in front of the previous dialog box. The means from the word reading task in Imbeau (1987) for the levels of three independent variables which were found to be significant factors (age group was not included in this routine, as it was already included in the Options menu) are shown in Table 74). Since the actual character luminance levels in nits varied with color, the appropriate luminance value for a color selected (Table 76) is displayed in the additional parameter area of the status window, along with the settings of the other two parameters (i.e., color and character size).

The other three entries in this subcategory are based on means from the two studies which utilized the 1985 Cadillac Sedan deVille (Dingus, 1986; Hayes et al., 1988). In all cases, the target information was presented in a digital LED display in the dashboard area of the vehicle.

Table 75. Primarily visual task data

	Read Odometer	Check Remaining Fuel	Check Speedometer		
Task completion time (s)	4.484	1.99	4.763	1.07	2.052
Hand-off-wheel time (s)	0.0858	n.a.	0.356	n.a.	0.00871
Number of glances to IP	2.062	1.52	2.195	1.26	1.208
Av. glance to IP (s)	1.367	1.04	1.336	0.62	0.931
Total glance to IP (s)	2.424	1.58	2.885	0.78	1.056
Av. glance to roadway (s)	0.621	0.37	0.493	0.32	0.497
Av. transition time (s)	0.0765	n.a.	0.0817	n.a.	0.0819
Sources	2	1	2	1	2
1 Dingus (1987)					
2 Hayes et al. (1988)					
		Check Warning Lights	Check Driver side Mirror	Check Passenger side Mirror	Check Rearview Mirror
Task completion time (s)	2.24	4.114	n.a.	n.a.	1.30
Hand-off-wheel time (s)	n.a.	0.000	n.a.	n.a.	n.a.
Number of glances to IP	2.12	2.167	n.a.	n.a.	1.31
Av. glance to IP (s)	0.83	1.348	1.06	1.12	0.75
Total glance to IP (s)	1.75	2.640	n.a.	n.a.	0.98
Av. glance to roadway (s)	0.52	0.382	n.a.	n.a.	0.37
Av. transition time (s)	n.a.	0.0805	n.a.	n.a.	n.a.
Sources	1	2	3	3	1
3 Rockwell (1983)					

File Edit **Task** Options

Status	
Task:	Speedometer
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	2.05
Hand-Off:	0.01
Num.IPG:	1.21
Aug.IPG:	0.93
Total IPG:	1.06
Aug.DRV:	0.50
AuTrans:	0.08
Figure of Merit	
Visual:	12.64
Manual:	0.10
Overall:	8.88
Adjusted:	8.88
Angles off Boresight	
Horizontal:	32.63
Vertical:	32.05

**Primarily visual; No manual demand**  
**Information is always available**

**Check-reading (digital)**

- Labels
- Odometer
- Remaining Fuel in Gallons
- Speedometer

**Detection**

- Rearview Mirror
- Driver's side Mirror
- Passenger's side Mirror
- Warning Lights

Figure 77. Primarily visual task dialog box

Status	
<b>Task:</b>	Check-reading
<b>Char Color</b>	Green
<b>Luminance</b>	7.43
<b>Char Size</b>	7.00
<b>Age:</b>	All Ages
<b>Gender:</b>	Both
<b>Workload:</b>	All Levels
<b>Task Time:</b>	3.11
<b>Hand-Off:</b>	0.00
<b>Num.IPG:</b>	1.00
<b>Avg.IPG:</b>	1.39
<b>Total IPG:</b>	1.39
<b>Avg.DRU:</b>	1.72
<b>AuTrans:</b>	0.11
<b>Figure of Merit</b>	
<b>Visual:</b>	22.32
<b>Manual:</b>	0.00
<b>Overall:</b>	15.62
<b>Adjusted:</b>	15.62
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	32.63
<b>Vertical:</b>	32.05

<b>Character Color</b>		<b>Character Luminance</b>	
<input type="radio"/> Blue Green		<input checked="" type="radio"/> High	
<input checked="" type="radio"/> Green Corvette		<input type="radio"/> Low	
<input type="radio"/> Ochre		<b>Character Size (Arc min @ eye)</b>	
<input type="radio"/> Light Blue		<input checked="" type="radio"/> 7	
<input type="radio"/> Image Red		<input type="radio"/> 11	
<input type="radio"/> Warm Red		<input type="radio"/> 17	
<input type="radio"/> White		<input type="radio"/> 25	
<input type="radio"/> Amber		<input type="button" value="OK"/>	

Figure 78. Check-reading task dialog box

Table 76. Luminance values for each character color (Imbeau, 1987)

Color	Brightness	Obtained Y (nits)	Corrected Y (nits)	$\Delta Y$ %
BLUGR	Low	2.17	2.16	0.5
	High	8.34	8.32	0.2
GRCOR	Low	1.65	1.64	0.6
	High	7.40	7.43	0.4
OCHRE	Low	2.21	2.28	3.2
	High	20.3	20.71	2.0
LIBLU	Low	1.67	1.67	0.0
	High	7.96	7.93	0.4
IMRED	Low	1.76	1.83	3.9
	High	15.30	15.74	0.9
WARD	Low	4.09	4.25	3.9
	High	48.00	49.23	2.6
WHITE	Low	3.89	4.08	4.9
	High	20.8	21.40	2.9
AMBER	Low	3.23	3.34	3.4
	High	29.6	30.16	1.2

**1.2. Visual detection** In this subcategory, drivers checked to determine whether a target object was present in the display. For the first entry, drivers checked across the lower dashboard area for a lit warning light; whereas in the other entries, drivers checked for other vehicles in the side or interior rearview mirrors. The side mirror checking tasks were defined by Rockwell (1983) as “natural looks” which were glances made without an experimenter instruction, e.g., sampling just prior to entry onto a freeway.

## *2. Primarily manual tasks*

The IP tasks under this category (Figure 79, Table 77), in contrast to those in the previous category, exerted minimal VAD and consisted of locating, reaching, and activating a distinct control (without micro-level selection).

**2.1. Turn signal indicator** The first entry in the dialog box, turn signal indicator, required almost no glance to IP, as drivers were often able to activate without looking for it.

**2.2. Locate & simple manipulate** IP tasks in this subcategory involved a single control with two discrete states (interior and map lights), a horizontal dial (sentinel), or a slide control (center vent). Because experimental subjects were instructed to move it from one limit to the other limit for the data on the latter two controls, their operations were considered identical to the operation of a two state switch of the first and thus included in this category.

**2.3. Manual delay** The last two entries required, after an appropriate control was located and reached, the control to be held down for a period of time until the power window moved to a desired state.

Status	
Task:	Sentinel
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	6.28
Hand-Off:	4.60
Num.IPG:	2.27
Avg.IPG:	1.06
Total IPG:	2.51
Avg.DRU:	1.18
AuTrans:	0.12
Figure of Merit	
Visual:	21.40
Manual:	50.58
Overall:	30.15
Adjusted:	30.15
Angles off Boresight	
Horizontal:	26.72
Vertical:	11.76

Primarily manual, requiring minimal or no glance

- Turn Signal (stalk)
- Stalk-end Button, e.g., cruise control set
- Interior Light (dashboard)
- Map Light (ceiling)
- Adjusting Sentinel (dashboard)
- Adjusting Center Vent (dashboard)
- Adjust Driver's side Power Window
- Adjust Passenger's side Power Window

OK

Figure 79. Primarily manual task dialog box

Table 77. Primarily manual task data

	Turn Signal	Press Stalk-end Button	Turn on Interior Light	Turn on Map Light
Task completion time (s)	0.64	1.871	2.725	3.474
Hand-off-wheel time (s)	n.a.	1.119	1.666	2.104
Number of glances to IP	0.63	0.354	1.042	1.500
Av. glance to IP (s)	0.30	0.280	0.452	0.840
Total glance to IP (s)	0.38	0.354	0.560	1.178
Av. glance to roadway (s)	n.a.	1.307	1.149	0.685
Av. transition time (s)	n.a.	0.0295	0.0840	0.136
Sources	1	2	2	2
1 Dingus (1987)				
2 Hayes et al. (1988)				

side	Open		Driver sidePass.			
	Adjust Sentinel	Center Vent	Power Window	Power Window		
Task completion time (s)	4.11	5.620	2.35	4.478	4.355	5.824
Hand-off-wheel time (s)	n.a.	3.851	n.a.	2.689	3.518	4.616
Number of glances to IP	2.51	2.271	1.83	2.125	2.104	3.143
Av. glance to IP (s)	1.01	1.071	0.62	1.076	0.693	0.796
Total glance to IP (s)	2.38	2.349	1.13	2.044	1.613	2.471
Av. glance to roadway (s)	0.76	1.176	0.60	0.730	1.043	0.766
Av. transition time (s)	n.a.	0.103	n.a.	0.0821	0.128	0.153
Sources	1	2	1	2	2	2
1 Dingus (1987)						
2 Hayes et al. (1988)						

### *3-7. Adjustment and selection tasks*

IP tasks which involved some type of adjustment or selection were categorized on the basis of their control and display characteristics and types of feedback. A control or display was considered to be of a continuous type, if any point along the continuum (between the limits) could be selected; whereas a discrete control consisted of a discrete number of control positions or settings. The definition of a discrete visual display was broader and was used liberally to include labelling for discrete positions of a control, i.e., no separate display existed for visual feedback. Mirrors were also considered a (continuous) display although their "display" contents were mere reflected images of an object. For some IP tasks, the types of feedback normally available in their operations were not complete in the studies where their data were collected. Such cases are noted individually in detail.

#### *3. Continuous control / continuous display tasks*

The first category belonging to this class of IP tasks contains three tasks (Figure 80) which used the middle radio in the auxiliary instrument panel (Figure 9) of Hayes et al. (1988) and the driving simulator experiments. The radio was of a traditional design and consisted of two rotary knobs for tuning and volume adjustment and a horizontal moving pointer display. Because this type of radio is substantially less accurate for visually selecting a particular frequency than radios with a digital frequency display, the tuning operation is more dependent on an auditory feedback. Users should be cautioned that because the auditory feedback was unavailable in both studies that provided these data, the means (Table 78) can only be considered estimates.

#### *4. Continuous control / discrete display tasks*

This second category of adjustment tasks is further divided on the basis of specific types of continuous control (Figure 81).

**4.1. Rotary control with detent** In this subcategory, drivers selected a specified position on the rotary control. Although these tasks were categorized as a discrete display, the only visual feedback

Status	
Task:	On; Tune; Volume
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	11.52
Hand-Off:	9.59
Num. IPG:	4.75
Avg. IPG:	1.34
Total IPG:	6.01
Avg. DRU:	0.75
AuTrans:	0.13
Figure of Merit	
Visual:	49.07
Manual:	105.48
Overall:	65.99
Adjusted:	65.99
Angles off Boresight	
Horizontal:	26.72
Vertical:	11.76

One example in this type of interface is conventional radios with rotary tuning knob and horizontal pointer.

- Tuning only
- Select FM/AM and tune
- Turn on, tune, and adjust volume

**OK**

Figure 80. Continuous control / continuous display task dialog box

**Table 78. Continuous control / continuous display task data**

Conventional radio Rotary knobs Horizontal pointer	Tune to Frequency	Select FM/AM and Tune	Turn on, Tune, and Turn volume	
Task completion time (s)	5.318	11.797	6.905	10.860
Hand-off-wheel time (s)	4.396	9.591	5.565	8.842
Number of glances to IP	2.625	5.667	2.953	4.750
Av. glance to IP (s)	1.555	1.297	0.965	1.358
Total glance to IP (s)	3.625	7.093	2.721	5.847
Av. glance to roadway (s)	0.538	0.555	0.889	0.745
Av. transition time (s)	0.121	0.115	0.120	0.117
Sources	1	1	2	1
1 Hayes et al. (1988)				
2 Kurokawa et al. (1989)				

⌘ File Edit **Task** Options

Status	
Task:	Consecutive Rot.
#Positions	6
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	4.61
Hand-Off:	3.31
Num.IPG:	1.87
Avg.IPG:	1.28
Total IPG:	2.39
Avg.DRU:	0.63
AuTrans:	0.12
Figure of Merit	
Visual:	24.01
Manual:	36.37
Overall:	27.71
Adjusted:	27.71
Angles off Boresight	
Horizontal:	26.72
Vertical:	11.76

**Rotary Selector Control**

Consecutive Labels  
 Random Labels

Number of Positions

**Slide Control, e.g., graphic equalizer adjustment**

High accuracy adjustment  
 Step-wise adjustment  
 Low accuracy adjustment

**Visual Radio Tuning (deflection knob & digital disp.)**

Select AM/FM and tune  
 Turn on, tune, and adjust volume

Figure 81. Continuous control / discrete display task dialog box

for positions was the labels on the control itself (the tactile feedback was provided by detent). The two rotary knobs used in Hayes et al. (1988) and in the driving simulator experiments were located in the middle of the auxiliary instrument panel (Figure 9), and one had 4 positions while the other had 9 positions. Each position was labelled with both randomly selected letters of the alphabet and consecutive numbers. Regression analyses were performed to provide equations for each label type condition that would allow an interpolation of the task performance measures for the number of positions other than 4 and 9 (Tables 79 and 80).

When selecting these tasks, users should select the type of position labelling in which they are interested and enter the number of positions (Figure 81).

**4.2. Slide control with detent** The IP tasks under this subcategory involved adjustment of vertical slide controls for the graphic equalizer of the middle radio in the auxiliary instrument panel (Figure 9). These controls, too, had no other display for feedback, except the grating behind the slide control for visual feedback and detent for tactile feedback. (For an actual system, an auditory feedback is available.) These tasks were divided on the basis of adjustment accuracy: (1) fine (to a specific position), (2) step-wise (by a number of detent clicks to be moved), and (3) gross (to a control limit). The means are shown in Table 81.

**4.3. Radio tuning** The IP tasks under this subcategory utilized the top radio in the auxiliary instrument panel (Hayes et al., 1988; Kurokawa, et al., 1989), and involved tuning to a specific frequency with a deflection knob and a digital display. The first entry involved selection of 1 of 8 similarly sized buttons (AM/FM) and tuning to a specified frequency; whereas the second involved turning a rotary knob to power on, tuning to a specified frequency, and turning the first knob. As mentioned earlier in category 3, radios with a digital frequency display allow drivers to tune accurately to a particular frequency with visual feedback alone, and these means are thus valid for visual tuning. If tuning was done solely with auditory feedback, the values collected from this type of radio should be similar to the values from the radios of category 3 (if with auditory feedback alone),

Table 79. Continuous control / discrete display task data (1)

Rotary control with detente  
Labelled with random letters of alphabet

Number of positions	4	4	9
Task completion time (s)	3.505	3.128	4.603
Hand-off-wheel time (s)	2.092	1.578	3.259
Number of glances to IP	1.646	1.288	2.218
Av. glance to IP (s)	1.252	0.931	1.354
Total glance to IP (s)	1.909	1.145	2.719
Av. glance to roadway (s)	0.523	0.784	0.471
Av. transition time (s)	0.112	0.121	0.112

Sources	1	2	1
1 Hayes et al. (1988)			
2 Kurokawa et al. (1989)			

Regression results

Task completion time =  $2.628 + 0.219 * N$

Hand-off-wheel time =  $1.158 + 0.234 * N$

Number of glances to IP =  $1.188 + 0.114 * N$

Average length of glances to IP =  $1.170 + 0.0204 * N$

Total glance to IP =  $1.260 + 0.162 * N$

Average length of glances to the roadway =  $0.565 + 0.0104 * N$

Average eye transition time =  $0.113 + 0.000188 * N$

Table 80. Continuous control / discrete display task data (2)

Rotary control with detente  
Labelled with consecutive numbers

Number of positions	4	4	9	9
Task completion time (s)	3.093	2.985	4.178	3.678
Hand-off-wheel time (s)	2.035	1.708	2.877	2.403
Number of glances to IP	1.596	1.296	2.153	1.696
Av. glance to IP (s)	1.152	0.889	1.199	0.981
Total glance to IP (s)	1.729	1.092	2.373	1.491
Av. glance to roadway (s)	0.477	0.799	0.514	0.735
Av. transition time (s)	0.115	0.121	0.113	0.120
Sources	1	2	1	2
1 Hayes et al. (1988)				
2 Kurokawa et al. (1989)				

Regression results

Task completion time =  $2.225 + 0.217 * N$

Hand-off-wheel time =  $1.360 + 0.169 * N$

Number of glances to IP =  $1.151 + 0.111 * N$

Average length of glances to IP =  $1.115 + 0.00931 * N$

Total glance to IP =  $1.214 + 0.129 * N$

Average length of glances to the roadway =  $0.447 + 0.00747 * N$

Average eye transition time =  $0.115 + 0.000231 * N$

**Table 81. Continuous control / discrete display task data (3)**

Slide control with detente Type of movement	Gross Adjustment		Step-wise Adjustment		Fine Adjustment	
Task completion time (s)	3.445	3.279	4.851	5.458	4.414	4.422
Hand-off-wheel time (s)	2.241	2.029	3.606	3.797	3.259	3.316
Number of glances to IP	1.393	1.188	2.278	1.938	1.779	1.354
Av. glance to IP (s)	1.130	0.769	1.283	0.963	1.038	0.918
Total glance to IP (s)	1.587	0.886	2.828	1.819	1.821	1.190
Av. glance to roadway (s)	0.816	1.068	0.539	1.206	1.143	1.721
Av. transition time (s)	0.118	0.123	0.117	0.149	0.116	0.125

<b>Sources</b>	1	2	1	2	1	2
1 Hayes et al. (1988)						
2 Kurokawa et al. (1989)						

Radio with digital display, deflection tuning knob, and rotary volume	Select FM/AM and Tune		Turn on, Tune, and Turn volume
Task completion time (s)	19.219	11.878	18.186
Hand-off-wheel time (s)	15.120	10.206	13.341
Number of glances to IP	9.117	5.766	8.750
Av. glance to IP (s)	1.308	0.859	1.146
Total glance to IP (s)	11.702	4.778	10.107
Av. glance to roadway (s)	0.574	0.829	0.587
Av. transition time (s)	0.113	0.122	0.110

<b>Sources</b>	1	2	1
1 Hayes et al. (1988)			
2 Kurokawa et al. (1989)			

since the only relevant difference between the two types would be their tuning knob, i.e., a deflection knob versus a rotary knob.

### *5. Discrete control / continuous display tasks*

The third category in the adjustment class of IP tasks consists of three subcategories, which are distinct in their operations (Figure 82).

**5.1. Rate pushbuttons** These adjustment tasks were based on the LED segmented bar display of the auxiliary instrument panel (Figure 9) in Hayes et al. (1988) and the driving simulator experiments. In these tasks, the display's control logic was set so that the lit LED element continued to move up or down when the appropriate rate pushbutton, i.e., up or down button, remained depressed. (This feature was intended to simulate a continuous bar display.) The three levels of adjustment accuracy were same as in category 4.2 tasks: (1) fine (to a specific position), (2) step-wise (by a specific number of increments to be increase or decreased), and (3) gross (to a display limit). The means from both studies are shown in Table 82.

**5.2. Power side mirrors** These tasks involved delicate adjustments of a power side mirror using the four directional buttons on the dashboard of Cadillac Sedan deVille in Dingus (1986) and in Hayes et al. (1988), and the mirror was considered a continuous display.

**5.3. Set cruise control** In Dingus (1986), experimental subjects were instructed to set the cruise control to a certain speed. The task involved (1) turning on the cruise control with a switch that was located on the dashboard to the right of the steering wheel, (2) locating the engage button at the end of the turn signal indicator stalk, (3) increasing speed with the accelerator, and (4) pressing the engage button earlier located.

<b>Status</b>	
<b>Task:</b> Driver Power Mirr	<p>Rate Pushbutton &amp; Bar LED tasks usually require a buttonpress to move a graphics display in the direction of the press. They are often used on CRT displays of radio and HVAC functions.</p> <p>Power Mirror tasks involve the adjustment of a side mirror using a joystick or a combination of directional controls. The data to be estimated here are based on dash-mounted 4 directional pushbuttons.</p> <p>Accelerate in Cruise refers to a discrete control adjustment to set a desired speed on the cruise control while monitoring the speedometer.</p> <p><b>Rate Pushbuttons (LED bar display)</b></p> <ul style="list-style-type: none"> <li><input type="radio"/> High accuracy adjustment</li> <li><input type="radio"/> Step-wise adjustment</li> <li><input type="radio"/> Low accuracy adjustment</li> </ul> <p><b>Power Side Mirrors</b></p> <ul style="list-style-type: none"> <li><input checked="" type="radio"/> Driver's side</li> <li><input type="radio"/> Passenger's side</li> <li><input type="radio"/> Set speed with Cruise Control</li> </ul> <p style="text-align: right;"><b>OK</b></p>
<b>Age:</b> All Ages	
<b>Gender:</b> Both	
<b>Workload:</b> All Levels	
<b>Task Time:</b> 9.43	
<b>Hand-Off:</b> 7.86	
<b>Num.IPG:</b> 6.08	
<b>Avg.IPG:</b> 0.80	
<b>Total IPG:</b> 4.60	
<b>Avg.DRV:</b> 0.52	
<b>RuTrans:</b> 0.12	
<b>Figure of Merit</b>	
<b>Usual:</b> 51.46	
<b>Manual:</b> 86.40	
<b>Overall:</b> 61.94	
<b>Adjusted:</b> 61.94	
<b>Angles off Boresight</b>	
<b>Horizontal:</b> 32.63	
<b>Vertical:</b> 32.05	

Figure 82. Discrete control / continuous display task dialog box



## *6. Discrete control / discrete display tasks*

The fourth category of the adjustment class of IP tasks contains the greatest variety of tasks (Figure 83), as this control / display combination seems to be more commonly found in the recent years.

**6.1. Select 1 of N & check-read** This subcategory is a variation of tasks in category 1 in that a check-reading element is preceded by micro-level selection of 1 of N discrete controls. The means are shown in the top half of Table 83. The first entry in this subcategory, time, involved a selection from 8 randomly labelled buttons of similar size (on the top radio of the auxiliary instrument panel, Figure 9); whereas the other three entries involved a selection from 4 randomly labelled buttons of similar size (the fuel data center on the Cadillac Sedan deVille's dashboard). Both check-reading elements were for numbers displayed digitally.

**6.2. Rate pushbuttons** There are two types of IP tasks in this subcategory. The first entry involves the temperature adjustment on the climate control center of the Cadillac Sedan deVille in Dingus (1986) and in Hayes et al. (1988), and experimental subjects were instructed to increase or decrease the digitally displayed interior temperature with horizontally arranged up and down buttons. The second type uses the same LED segmented bar display as in category 5.1, except that the display's control logic is now set so that the lit LED element moved only one per a button press. The three levels of adjustment accuracy were the same: (1) fine, (2) step-wise, and (3) gross.

**6.3. Automatic radio tuning** This subcategory of IP tasks involved a selection of 1 of 2 buttons, followed by auditory or visual determination of whether the automatically selected station was appropriate. Due to the absence of auditory feedback, the means of this subcategory are merely estimates (Table 84).

**6.4. Telephone dialing** The pushbutton telephone dialing tasks were, in effect, a selection of N of 12 sequentially numbered buttons. Regression equations with the number of digits to be dialed

Status	
Task:	Push Telephone
# digits	9
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	8.61
Hand-Off:	7.10
Num. IPG:	4.27
Avg. IPG:	1.35
Total IPG:	5.24
Avg. DRU:	0.54
AUTrans:	0.10
Figure of Merit	
Visual:	44.82
Manual:	78.06
Overall:	54.79
Adjusted:	54.79
Angles off Boresight	
Horizontal:	32.63
Vertical:	32.05

**Select and check-read**

- Time
- Fuel data

**Rate Pushbutton Tasks**

- Adjust HVAC temperature

**LED Bar Display**

- High accuracy adjustment
- Step-wise adjustment
- Low accuracy adjustment

- Select N from M pushbuttons
- Automatic Radio Tuning, e.g., scan & seek

Telephone Dialing:

Number of digits to be dialed

Figure 83. Discrete control / discrete display task dialog box

**Table 83. Discrete control / discrete display task data (1)**

	Select & Read Time	Select & Read Fuel economy	Select & Read Fuel range	Select & Read Fuel data	
Task completion time (s)	7.344	4.023	3.82	3.95	6.958
Hand-off-wheel time (s)	3.593	1.706	n.a.	n.a.	2.997
Number of glances to IP	3.542	1.875	2.48	2.54	3.597
Av. glance to IP (s)	1.405	0.875	1.14	1.19	1.313
Total glance to IP (s)	4.664	1.553	2.87	3.0	4.446
Av. glance to roadway (s)	0.447	0.739	0.57	0.53	0.488
Av. transition time (s)	0.118	0.122	n.a.	n.a.	0.0970

Sources	2	3	1	1	2
1 Dingus (1987)					
2 Hayes et al. (1988)					
3 Kurokawa et al. (1989)					

Discrete controls (Up & Down)	Discrete LED bar display				
	Adjust Temperature	Gross Adjustment	Step-wise Adjustment	Fine Adjustment	
Task completion time (s)	4.89	6.873	5.160	3.868	6.331
Hand-off-wheel time (s)	n.a.	5.377	3.884	3.015	4.932
Number of glances to IP	3.18	3.750	2.667	1.667	3.417
Av. glance to IP (s)	1.10	1.342	1.320	1.097	1.243
Total glance to IP (s)	3.50	4.529	3.128	1.778	3.685
Av. glance to roadway (s)	0.59	0.412	0.442	0.943	0.510
Av. transition time (s)	n.a.	0.0863	0.107	0.107	0.108

Sources	1	2	2	2	2
1 Dingus (1987)					
2 Hayes et al. (1988)					

**Table 84. Discrete control / discrete display task data (2)**

<b>Automatic Radio Tuning</b>	<b>Select Frequency scan</b>	<b>Select Seek station</b>	
Task completion time (s)	4.704	3.032	5.080
Hand-off-wheel time (s)	2.664	1.724	2.571
Number of glances to IP	2.083	1.250	1.938
Av. glance to IP (s)	1.498	1.033	1.488
Total glance to IP (s)	2.917	1.150	2.742
Av. glance to roadway (s)	0.508	0.835	0.830
Av. transition time (s)	0.114	0.133	0.116
<b>Sources</b>	<b>1</b>	<b>2</b>	<b>1</b>
1 Hayes et al. (1988)			
2 Kurokawa et al. (1989)			

as the regressor were performed with the data for 1, 6, 9, and 13 digits. As shown in Table 85, there exists a significant linear relationship between the number of digits to be dialed and dependent variables. When users select this task, the text box to enter the number of digits becomes highlighted. As the number of digits is entered, the dependent measures and figures of merit are updated.

**6.5. Select M of N** This subcategory was intended as a generic case of a selecting M buttons from N buttons (Figure 84). When this task is selected in the dialog box, another dialogbox will appear in front of it, containing a brief description and two text entry boxes to enter M and N. Shown in Table 86 are the means (Hayes et al., 1988; Kurokawa et al., 1989) of tasks to select one of N randomly labelled buttons in the Pontiac pushbutton control center, located in the auxiliary instrument panel (Figure 9), while the means for select M of N tasks using the same instrument and the regression results are shown in Table 87.

### *7. Auditory feedback tasks*

The last category of the adjustment class of IP tasks included in the current version of IPanalyzer contains five tasks whose primary type of feedback is auditory (Figure 85). The data for these tasks was gathered using a continuous control, and the means from Hayes et al. (1988) are estimates due to the absence of auditory feedback (Table 88).

### *8. Complex manipulative tasks*

This category of IP tasks require relatively high CMD due to the complexity of manipulation involved (Figure 86). For example, the task of inserting a cassette tape into a tape deck required drivers to locate a tape, orient it, and insert it into the deck. Tasks under this category are distinct from those in category 2, because the manipulation in this category exerts VAD. The means are shown in Table 89.

Table 85. Discrete control / discrete display task data (3)

Dialing pushbutton telephone Number of digits	1	6	9	13	
Task completion time (s)	3.279	6.607	9.024	10.950	9.759
Hand-off-wheel time (s)	1.810	5.295	7.298	9.480	8.629
Number of glances to IP	1.438	3.250	4.271	5.667	5.363
Av. glance to IP (s)	1.354	1.318	1.406	1.289	0.981
Total glance to IP (s)	1.818	3.787	5.638	6.734	4.513
Av. glance to roadway (s)	0.633	0.564	0.588	0.468	0.735
Av. transition time (s)	0.108	0.102	0.104	0.103	0.111
Sources	1	1	1	1	2
1 Hayes et al. (1988)					
2 Kurokawa et al. (1989)					

Regression results

Task completion time =  $2.741 + 0.652 * N$  ( $r^2 = 0.992$ )

Hand-off-wheel time =  $1.309 + 0.643 * N$  ( $r^2 = 0.996$ )

Number of glances to IP =  $1.105 + 0.352 * N$  ( $r^2 = 1.00$ )

Total glance to IP =  $1.425 + 0.423 * N$  ( $r^2 = 0.983$ )

Average length of glances to the roadway =  $0.652 + 0.00122 * N$  ( $r^2 = 0.791$ )

Status	
Task:	Select M of N
Presses	1
Buttons	12
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	4.19
Hand-Off:	2.30
Num.IPG:	1.98
Avg.IPG:	1.23
Total IPG:	2.35
Avg.DRU:	0.45
AUTrans:	0.12
Figure of Merit	
Visual:	23.58
Manual:	25.31
Overall:	24.10
Adjusted:	24.10
Angles off Boresight	
Horizontal:	32.63
Vertical:	32.05

The attentional demand of Select N from M tasks is determined by the number of activations per task and the number of controls in the group. For example, selecting a preset radio station might be: Select 1 of 6.

Number of activations per task:

Number of surrounding buttons:

Figure 84. Select M of N task dialog box

Table 86. Select 1 of N task data and regression results

Select 1 of N pushbuttons (Bottom radio)

N	3	6	12	12	12	
Task completion time (s)	3.553	3.188	4.127	3.272	4.724	4.068
Hand-off-wheel time (s)	1.917	1.416	2.396	1.588	2.657	1.597
Number of glances to IP	1.558	1.188	1.752	1.338	2.080	1.575
Av. glance to IP (s)	1.091	0.985	1.266	1.169	1.279	0.971
Total glance to IP (s)	1.596	0.848	2.134	0.916	2.543	1.407
Av. glance to roadway (s)	0.735	0.938	0.666	0.811	0.615	0.867
Av. transition time (s)	0.116	0.126	0.118	0.127	0.118	0.129
Sources	1	2	1	2	1	2
1 Hayes et al. (1988)						
2 Kurokawa et al. (1989)						

Regression results

Task completion time = 2.846 + 0.115 \* N

Hand-off-wheel time = 1.283 + 0.0849 \* N

Number of glances to IP = 1.346 + 0.0529 \* N

Average length of glances to IP = 0.968 + 0.0221 \* N

Total glance to IP = 1.222 + 0.0936 \* N

Average length of glances to the roadway = 0.693 + 0.00811 \* N

**Table 87. Select M of N task data and regression results**

**Select M of N pushbuttons**

M	1	1	1	2	3
N	3	6	12	12	12
Task completion time (s)	3.010	3.810	4.138	5.138	7.550
Hand-off-wheel time (s)	1.458	1.911	2.262	3.505	4.435
Number of glances to IP	1.462	1.727	1.960	2.521	4.083
Av. glance to IP (s)	0.995	1.159	1.214	1.210	1.208
Total glance to IP (s)	1.397	1.942	2.293	2.744	4.699
Av. glance to roadway (s)	0.674	0.636	0.598	0.615	0.409
Av. transition time (s)	0.106	0.107	0.107	0.108	0.097

Sources: Hayes et al. (1988)

**Regression results**

Task completion time =  $0.945 + 1.682 * M + 0.131 * N$

Hand-off-wheel time =  $0.0148 + 1.221 * M + 0.0888 * N$

Number of glances to IP =  $0.354 + 0.976 * M + 0.545 * N$

Average length of glances to IP =  $0.954 - 0.0166 * M + 0.0246 * N$

Total glance to IP =  $0.134 + 1.035 * M + 0.0983 * N$

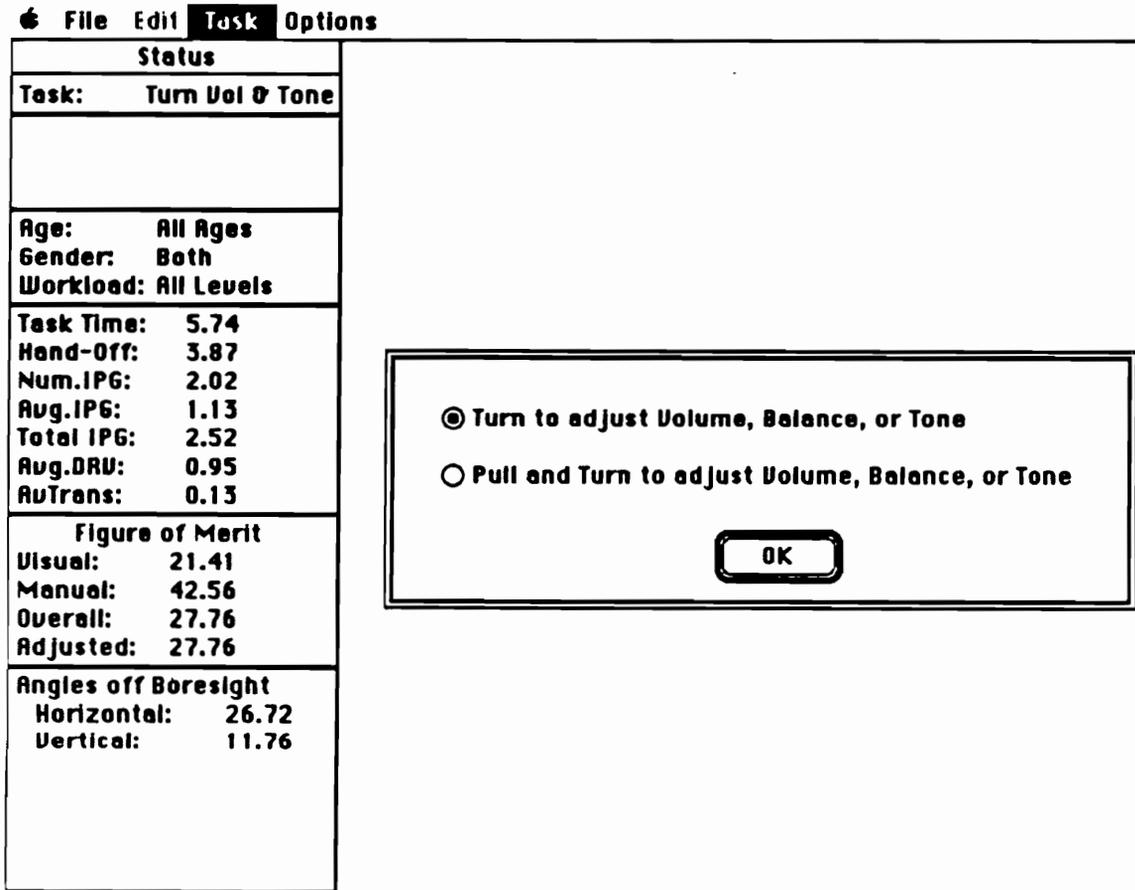


Figure 85. Auditory feedback task dialog box

**Table 88. Auditory feedback task data**

	Reset Balance	Reset Tone	Turn Balance	Pull & Turn Balance	Turn Volume
Task completion time (s)	3.73	2.57	6.357	6.253	5.081
Hand-off-wheel time (s)	n.a.	n.a.	4.175	4.218	3.122
Number of glances to IP	2.59	1.73	2.406	2.375	2.021
Av. glance to IP (s)	0.86	0.92	1.291	1.140	1.147
Total glance to IP (s)	2.23	1.59	2.943	2.646	2.358
Av. glance to roadway (s)	0.82	0.65	1.206	1.231	0.948
Av. transition time (s)	n.a.	n.a.	0.117	0.112	0.113
Sources	1	1	2	2	2
1 Dingus (1987)					
2 Hayes et al. (1988)					

File Edit **Task** Options

Status	
Task:	Rearview Mirror
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	5.04
Hand-Off:	3.77
Num.IPG:	3.17
Avg.IPG:	0.92
Total IPG:	2.49
Avg.DRU:	0.53
AuTrans:	0.09
Figure of Merit	
Visual:	25.35
Manual:	41.51
Overall:	30.20
Adjusted:	30.20
Angles off Boresight	
Horizontal:	32.63
Vertical:	32.05

Complex manipulative tasks may require several distinct manual operations or may require a large number of glances to establish proper orientation.

Insert a Casette Tape
  Adjust (Interior) Rearview Mirror

Figure 86. Complex manipulative task dialog box

**Table 89. Complex manipulative task data**

	Insert Cassette tape	Adjust Rearview mirror	
Task completion time (s)	5.24	7.654	5.043
Hand-off-wheel time (s)	n.a.	6.443	3.774
Number of glances to IP	2.06	4.000	3.167
Av. glance to IP (s)	0.80	0.856	0.919
Total glance to IP (s)	1.64	3.393	2.490
Av. glance to roadway (s)	0.90	0.782	0.529
Av. transition time (s)	n.a.	0.122	0.0882
<b>Sources</b>	<b>1</b>	<b>1</b>	<b>2</b>
1 Dingus (1987)			
2 Hayes et al. (1988)			

### *9. Electronic navigation aid tasks*

The data on tasks involving the ETAK electronic navigation aid in Dingus (1986) were placed under a category separate from the typical adjustment class because of their relatively high cognitive demand. The dialog box for this routine contains brief descriptions of the device and radio buttons for a selection of specific tasks (Figure 87). The description of each task is provided in Table 90, and the means are shown in Table 91.

### *10. Touch panel display tasks*

Lastly, the data from the third driving simulator experiment were incorporated as another category (Figure 88). Actual touch panel display tasks presumably exert a high cognitive demand, as do the previous category, because various screens in a system often differ in format, e.g., the number and type of selections (or functions) that are available in each screen. The task performance measures for different combinations of label abbreviation and the number of controls in an instrument are obtained by the regression equations shown in Table 92. (The regression analyses used means, rather than raw data points. Although regressions using the raw data points are unlikely to result in  $r^2 = 1.00$ , the correlations are still expected to be high.)

 File Edit <b>Task</b> Options	
<b>Status</b>	
<b>Task:</b>	Navigation Aid
<b>Subtask:</b>	Adj Zoom
<b>Age:</b>	All Ages
<b>Gender:</b>	Both
<b>Workload:</b>	All Levels
<b>Task Time:</b>	5.93
<b>Hand-Off:</b>	4.12
<b>Num.IPG:</b>	2.91
<b>Aug.IPG:</b>	1.38
<b>Total IPG:</b>	4.16
<b>Aug.DRU:</b>	0.54
<b>AUTrans:</b>	0.12
<b>Figure of Merit</b>	
<b>Usual:</b>	34.05
<b>Manual:</b>	45.29
<b>Overall:</b>	37.42
<b>Adjusted:</b>	37.42
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	26.72
<b>Vertical:</b>	11.76

The data for the Electronic Navigation Tasks was collected using the ETAK Moving Map Navigation System.

The first three tasks are essentially check-reading tasks in that the information is normally displayed on the monitor. (Except for Current Direction which requires a judgement of the current direction based on the displayed direction).

The remaining tasks usually require control manipulations of the driver, along with judgement as to the appropriateness of the information displayed.

<input type="radio"/> Destination Direction	<input type="radio"/> Destination Distance
<input type="radio"/> Current Direction	<input checked="" type="radio"/> Adjust Zoom Level
<input type="radio"/> Correct Direction	<input type="radio"/> Roadway Distance
<input type="radio"/> Next Cross Street	<input type="radio"/> Roadway Name

Figure 87. Electronic navigation aid task dialog box

Table 90. Description of ETAK navigation aid tasks (Dingus, 1987)

Task	Classification and Abbreviated Name	Operator Requirements
Point in the direction of the destination	(Navigator) Destination Direction	<ul style="list-style-type: none"> <li>-- Locate direction to destination arrow on Navigator (always displayed)</li> <li>-- Point out of window in arrow direction</li> </ul>
Determine the distance to the destination	(Navigator) Destination Distance	<ul style="list-style-type: none"> <li>-- Locate distance number on Navigator (always displayed)</li> <li>-- Read number</li> </ul>
Determine the general vehicle heading	(Navigator) Heading	<ul style="list-style-type: none"> <li>-- Locate North arrow on Navigator (always displayed)</li> <li>-- Judge current direction relative to North</li> </ul>
Determine whether the direction of travel is appropriate to get to the destination	(Navigator) Appropriate Direction	<ul style="list-style-type: none"> <li>-- Locate direction to destination arrow on Navigator (always displayed)</li> <li>-- Look at current roadway being traveled and associated near roadways (always displayed for this task)</li> <li>-- Judge whether current roadway and direction are appropriate</li> </ul>

Table 90 (continued)

Task	Classification and Abbreviated Name	Operator Requirements
Set the proper Zoom-Level based on the destination distance	(Navigator) Zoom Level	<ul style="list-style-type: none"> <li>-- Look at distance number on navigator (always displayed)</li> <li>-- Look at Scale levels on Navigator (always displayed)</li> <li>-- Depress next higher scale level number than destination distance number</li> </ul>
Determine the name of the next cross street	(Navigator) Cross Street*	<ul style="list-style-type: none"> <li>-- Look at scale level number on navigator (always displayed)</li> <li>-- Look at navigator map display (always displayed) and determine whether a cross street appears</li> <li>-- Judge whether any cross street that appears based on the current scale level is the next cross street based on the current scale level</li> <li>-- Zoom-in or zoom-out if cross street does not appear or if the cross street displayed is not likely to be the next cross street</li> <li>-- Read label if present or respond "no label appears"</li> </ul>

\* This task involves finding the next cross street, whether or not it would be used to get to the destination.

Table 90 (continued)

Task	Classification and Abbreviated Name	Operator Requirements
Determine the name of the appropriate near roadway to get to the destination	(Navigator) Roadway Name	<ul style="list-style-type: none"> <li>-- Look at navigator map display and find the destination star (always displayed for this task)</li> <li>-- Plan route from current point to destination</li> <li>-- Judge whether a scale change is required to determine the appropriate near turn-off roadway</li> <li>-- Zoom-in or zoom-out if required to find roadway</li> <li>-- Read label if present or respond "no label appears"</li> </ul>
Determine distance to the appropriate near roadway to get to the destination	(Navigator) Roadway Distance	<ul style="list-style-type: none"> <li>-- Locate appropriate near turn-off roadway as described above</li> <li>-- Interpolate distance to near roadway from knowledge of map scale</li> <li>-- State distance</li> </ul>

Table 91. Electronic navigation aid task data (Dingus, 1987)

ETAK electronic Navigation aid	Destination Direction	Destination Distance	Current Direction	Correct Direction
Task completion time (s)	1.99	2.34	5.72	3.72
Hand-off-wheel time (s)	n.a.	n.a.	n.a.	n.a.
Number of glances to IP	1.31	1.73	2.76	2.04
Av. glance to IP (s)	1.20	1.06	1.30	1.45
Total glance to IP (s)	1.57	1.83	3.58	2.96
Av. glance to roadway (s)	0.33	0.40	0.74	0.58
Av. transition time (s)	n.a.	n.a.	n.a.	n.a.

Sources: Dingus (1987)

ETAK electronic Navigation aid	Adjust Zoom level	Next Cross street	Roadway Distance	Roadway Name
Task completion time (s)	5.27	11.08	13.04	15.87
Hand-off-wheel time (s)	n.a.	n.a.	n.a.	n.a.
Number of glances to IP	2.91	5.21	5.78	6.52
Av. glance to IP (s)	1.40	1.66	1.53	1.63
Total glance to IP (s)	4.00	8.63	8.84	10.63
Av. glance to roadway (s)	0.54	0.54	0.63	0.65
Av. transition time (s)	n.a.	n.a.	n.a.	n.a.

Sources: Dingus (1987)

File Edit **Task** Options

Status	
Task:	Touch Panel Disp
# Buttons	9
Age:	All Ages
Gender:	Both
Workload:	All Levels
Task Time:	5.97
Hand-Off:	2.05
Num.IPG:	2.19
Avg.IPG:	0.97
Total IPG:	1.74
Avg.DRU:	0.85
AuTrans:	0.11
Figure of Merit	
Visual:	19.03
Manual:	22.54
Overall:	20.09
Adjusted:	20.09
Angles off Boresight	
Horizontal:	26.72
Vertical:	11.76

Number of Buttons within control cell

Level of Label Abbreviation

Single-Line

Double-Line

Triple-Line (Fully spelled)

Figure 88. Touch panel display task dialog box

**Table 92. Touch panel display task regression results**

**Task completion time (s) =**

**2.737 + 0.285 n for single-line abbreviation ( $r^2 = 0.994$ )**

**2.612 + 0.398 n for double-line abbreviation ( $r^2 = 0.998$ )**

**2.573 + 0.431 n for fully spelled labels ( $r^2 = 0.998$ )**

**Hand-off-wheel time (s) =**

**1.202 for single-line abbreviation**

**1.285 for double-line abbreviation**

**1.330 for fully spelled labels**

**Number of glances to IP =**

**1.186 + 0.111 n for single-line abbreviation ( $r^2 = 1.00$ )**

**1.071 + 0.177 n for double-line abbreviation ( $r^2 = 0.996$ )**

**1.150 + 0.166 n for fully spelled labels ( $r^2 = 0.993$ )**

**Average length of glances to IP (s) =**

**0.983 for single-line abbreviation**

**0.979 for double-line abbreviation**

**0.990 for fully spelled labels**

**Total glance to IP (s) =**

**1.584 for single-line abbreviation**

**1.752 for double-line abbreviation**

**1.815 for fully spelled labels**

**Average length of glances to the roadway (s) =**

**0.756 + 0.104 n for single-line abbreviation ( $r^2 = 1.00$ )**

**0.840 - 0.0406 n for double-line abbreviation ( $r^2 = 0.060$ )**

**0.781 + 0.00490 n for fully spelled labels ( $r^2 = 0.408$ )**

## Methods for estimating IP task performance

The primary objective of this portion of IPanalyzer is to develop procedures that can be used to estimate measures of driver IP task performance when no data are available for tasks of interest. The procedures are intended to be applicable to existing tasks for which no prior data exist as well as to prospective tasks that are yet to be designed and implemented. The latter application is of particular interest because the ability to predict task performance can aid the design and development of new technology instruments.

The general approach taken in developing these procedures was first to consider alternative means of defining an IP task. In the empirical model, a task of interest is defined by the interface characteristics. Its task elements are then implicitly defined by controls and displays that are involved in each step of the operation. Although this is a simple and straightforward way to specify an existing IP task, the use of existing instrument characteristics to define a task necessarily limits its ability to describe unconventional tasks that do not fit its terminology. The process of designing a new task should obviously not be constrained by the existing technology but be driven by requirements to optimize human-machine interface.

For the two methods that are described below, alternative means to describe an IP task, in a language that is not hardware specific and thus not limited to conventional interface designs, were explored. Using the alternative definitions, representative IP tasks with existing data were characterized, and driver performance measures were estimated based on the alternative description. The estimates were then compared with the actual values to examine the precision of a given prediction procedure. The main motivation behind these preliminary attempts to predict driver IP task performance is to understand the underlying mechanism better and to develop a more comprehensive and accurate model of driver activities.

### *Task estimate procedure*

Under the first method of IP task performance estimation, users directly estimate relevant dependent measures based on an understanding of a prospective task. As discussed earlier, an IP task can be characterized by its visual attentional demand (VAD) and concurrent manual demand (CMD). VAD might be assessed in terms of the difficulty of task elements and the complexity of a whole task, which is related to the number and variety of task elements. The difficulty of a task element is reflected by the length of a glance to the IP, i.e., the more difficult it is to execute the element, the longer a glance it requires. The average length of glances to the IP is then an indicator of the mean difficulty of task elements or the overall difficulty of the task. Similarly, the number of glances to IP is closely related to the number of task elements and thus the complexity of the task. If the difficulty of manipulation is directly related to the amount of time that a hand attends to an instrument, the magnitude of CMD can also be expressed in terms of hand-off-wheel time, i.e., a manual equivalent of total glance time to IP (plus transitions). Therefore, if these aspects of an IP task's demand characteristics are known, users should be able to make reasonable estimates of these dependent measures.

In this procedure, users are led through a series of four dialog boxes (Figures 89 through 92). The first three dialog boxes contains benchmark values, i.e., empirical values for various IP tasks, for each of the three relevant dependent variables: the average length of glances to IP, the number of glances to IP, and hand-off-wheel time. Estimates are made by comparing each aspect of a prospective task with that of existing tasks and by selecting values that seem closest to the task of interest. Once these three variables are set, the other four dependent variables and figures of merit are calculated, and a set of estimates is complete.

To aid the process of estimation, this procedure allows two sets of dependent measures to be manipulated. As can be seen in Figure 92, two columns of dependent measures and figures of merit are displayed in the status window. In each of the dialog boxes, there are also two columns of selection buttons or entry boxes, corresponding to each of the columns in the status window. This

<b>Representative Average IP Glance Times</b>	
<input type="radio"/> <input type="radio"/> 0.00	<b>Driver does not need to glance at task.</b>
<input type="radio"/> <input type="radio"/> 0.60	<b>Driver reads 2-digit speedometer.</b>
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 0.70	
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 0.80	<b>Driver adjusts power mirror, glancing between the mirror and the controls.</b>
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 0.90	
<input type="radio"/> <input type="radio"/>	
<input checked="" type="radio"/> <input type="radio"/> 1.00	
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input checked="" type="radio"/> 1.10	<b>Driver selects 1 of 5 pushbuttons, then retrieves digitally displayed information.</b>
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 1.20	
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 1.30	<b>Driver makes several discrete activations on a bar LED display.</b>
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 1.40	
<input type="radio"/> <input type="radio"/>	<b>Driver enters a 7-digit telephone number.</b>
<input type="radio"/> <input type="radio"/> 1.50	
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/>	
<input type="radio"/> <input type="radio"/> 1.65	<b>Driver determines, from a navigator display, the name of street to turn onto to get to destination.</b>

Figure 89. Task estimate dialog box (1)

**Representative Numbers of Glances to IP**

1.0 Driver reads a 2-digit digital speedometer.

2.0 Driver reads a 6-digit odometer.

3.0

4.0

5.0 Driver manually tunes radio with analog display.

6.0 Driver enters a long distance number on the telephone keypad.

7.0

8.0 Driver adjusts power mirror, glancing to mirror and controls.

9.0

10.0

Figure 90. Task estimate dialog box (2)

**Representative Hand-Off-Wheel Times**

- 0.0 Driver surveys status lights.
- 
- 1.0 Driver activates turn signal.
- 
- 2.0 Driver resets trip odometer.
- 
- 3.0 Driver adjusts rotary volume control.
- 
- 4.0 Driver adjusts rear view mirror.
- 
- 5.0
- 
- 6.0
- 
- 7.0 Driver enters a 7-digit number on the telephone keypad.
- 
- 8.0
- 
- 9.0 Driver adjusts power side mirror.
- 
- 10.0 Driver enters a long distance number on the telephone keypad.
- 

Figure 91. Task estimate dialog box (3)

Status		
Task:	Estimated	
Age:	All Ages	
Gender:	Both	
Workload:	All Levels	
Task Time:	4.20	5.25
Hand-Off:	3.00	4.00
Num.IPG:	2.00	2.50
Avg.IPG:	1.00	1.15
Total IPG:	2.00	2.88
Avg.DRU:	0.68	0.68
AuTrans:	0.11	0.11
Figure of Merit		
Visual:	18.49	25.08
Manual:	33.00	44.00
Overall:	22.84	30.76
Adjusted:	22.84	30.76
Angles off Boresight		
Horizontal:	32.63	
Vertical:	32.05	

If you wish to change any of the values you have entered, you may enter the value directly here.

Average Glance to IP ( Avg.IPG ):

Number of Glances to IP ( Num.IPG ):

Hand-Off-Wheel Time ( Hand-Off ):

Figure 92. Task estimate dialog box (4)

feature allows users, for instance, to use the first column as the lower limits of estimates and the other for the upper limits, or to create two different combinations of values and obtain the range of estimates.

When the task estimate procedure is selected from the Task menu, driver definition entries, i.e., age group, gender, and concurrent driving workload, instrument location, control label factors, and both sets of dependent measures are set to the identical set of default values. In each of the first three dialog boxes, users should examine the accompanying descriptions of benchmark values, move the cursor arrow to the selection button corresponding to a desired value, and click the mouse button. The radio button will be highlighted, the corresponding entry in the status window will be changed to the new value, and the other measures and figures of merit are updated. The fourth dialog box which contains text entry boxes allows users to enter values directly so that users can change values of all three relevant variables without moving to different dialog boxes or enter values which fall between the intervals of radio buttons in the first three dialog boxes. Users can, of course, move through the dialog boxes, forward and backward, as long as needed.

Once satisfied with the selections, users can exit the routine and change the levels of external factors or figure of merit coefficients in the Options menu. Users should note that the driver definition entries, instrument location, and control label factors are set to default when this routine is selected, and the figure of merit coefficients are the only parameters that are not reset on entry and remain the same while in the procedure. Hence, users are advised not to set any Options menu parameters, except the figure of merit and frequency of use routines, and to record any previous results of this procedure which they wish to maintain before selecting this procedure (as the values will be reset and lost).

**On-line help file** The following text is available as on-line aid for this procedure. To access the file, users should choose Help command from Apple menu, and open Task Estimate.HELP.

The task estimate procedure will synthesize expected driver performance measures for any IP task. The estimates will be made on a generic driving population under average driving workload conditions.

Three parameters must be entered:

- Average length of glances to IP (Avg.IPG)
- Number of glances to IP (Num.IPG)
- Hand-off-wheel time (Hand-Off)

These parameters may be determined empirically or by comparison to existing data. Explanations of each variable follow:

An average length of glances to IP reflects the mean difficulty of a given task, i.e., the difficulty in locating and acquiring visual information. Task difficulty may also depend on the probability of error and the need for accuracy.

The average length of glances to IP ranges approximately from 0.6 seconds for a simple check-reading or locating task to 1.6 seconds for extracting complex information from a map or electronic navigation aid. Some tasks do not require drivers to glance toward the instrument. For example, drivers usually do not look at the turn signal indicator when activating it, resulting in a glance time of 0 seconds.

Representative average lengths of glances for a variety of IP tasks are rank-ordered on the first screen. Read carefully the accompanying descriptions and click on the radio button what best represent your task.

The number of glances to IP is an indicator of the complexity of a task as a whole. Task complexity can be defined as the number of steps or task elements required to complete the task.

The number of glances to IP ranges approximately from 1.2 for checking a digital speedometer to 9 for tuning a radio to a specific frequency with a deflection tuning knob and a digital display, which is highly prone to overshoot. Select from representative numbers of glances that are shown in the second screen.

Hand-off-wheel time is the total time that a driver's hand is off the steering wheel to perform an IP task. Drivers often make several control adjustments for a given task, returning the hand to the steering wheel between each adjustment. Hand-off-wheel time thus reflects the concurrent manual demand of an IP task.

In general, the value of hand-off-wheel time is small (0.6 seconds) for simple activation tasks and large (10.0 seconds) for such complex tasks as tuning a radio with a digital display. Some check-reading and detection tasks, e.g., checking a speedometer or a rearview mirror, might not require hand movements, resulting in hand-off-wheel time of 0 seconds. Select from the representative values on the third screen.

### *Task analytic procedure*

This procedure to estimate driver IP task performance was developed to test an approach in characterizing an IP task different from the empirical model and the task estimate method. The concept of task analysis was borrowed from the domain of traditional industrial engineering and applied to a micro-level examination of individual IP tasks. The first step was to perform exhaustive analyses of existing IP tasks and to devise operational definitions, e.g., the sequence of events (or task elements) and the objective, or purpose, of each event.

The important distinction between the empirical model and this method is the way in which IP tasks were categorized. In the empirical model, tasks were grouped first by the instrument that they used. Instruments were then categorized by their interface characteristics, i.e., type of controls and displays which the instrument contained. (Recall that users specify an IP task by the instrument in the Directory routine and by going through a hierarchical selection tree in the Characteristics routine.) Differences in actual operations were either ignored when considered minor or used only when a bottom level differentiation among several tasks was needed. While interface characteristics provide an explicit and thus easy way to describe activities which are involved in an operation of an IP task, the very convenience might force one to look at the task only within the framework of existing types of instruments. (Some IP tasks may require certain creativity to design an optimal human-machine interface.)

The task analytic approach focused on behavioral characteristics as the top level differentiation criterion, especially because the eventual goal was to develop an instrument independent language to describe an IP task. Such a descriptive language would then allow the driver performance measures of a future IP task to be estimated, and in turn a potential design to be evaluated, beyond the constraints of an existing technology. It should also help researchers understand the underlying mechanism of driver-task interaction better. Eventually, a knowledge-based IP evaluation program that considers a prospective IP task described to it in this manner and that can suggest an optimal interface design might be developed.

All IP tasks with usable data were thus analyzed and decomposed into task elements which were categorized, on the basis of their behavioral characteristics, into fifteen categories. For each category, behavioral element means were then computed from the relevant elements of the existing data (Table 93). Many means were derived from the data of Hayes et al. (1988), as their data were often available at the micro level (i.e., many of their "generic tasks" were actually a task element in a conventional IP task) and thus most suitable for this approach. The following list of behavioral element categories was necessarily dictated by availability of the element means and is not expected to be comprehensive; however, it provides a reasonable model covering the conventional IP tasks.

**1. Visual detection and monitoring** This class of IP tasks is identical to category 1.2 of the empirical model: check for warning lights; check the driver-side, passenger-side, or interior rearview mirror. In this behavioral element, drivers scan a target area for the presence of an object, e.g., a warning light or another car. No further interpretation of the target object is made, and no manual demand exists.

**2. Check-reading** This class of IP tasks was included in category 1.1 of the empirical model: check odometer, digital speedometer, or remaining fuel in gallons. In this behavioral element, drivers direct eyes to a target area and extract information that is available at all time, e.g., a number in the above tasks or a word in the Imbeau (1987) study. No manual demand exists.

**3. Simple locate and reach** In this class of IP tasks, drivers locate a target object, reach for it, and manipulate it. Drivers are likely to locate the target visually before reaching for it; however, they may reach in the general direction and locate it with tactile feedback, or locate the target with a combination of visual and tactile feedbacks. The target is assumed to be separate and distinct from others in terms of control and location, and no selection is required within the target area (the manipulation is of minimal complexity, e.g., two discrete states (ON/OFF), and requires a minimal or no glance). The means included in this class are: activate (or deactivate) interior or overhead map lights; move a sentinel dial; open or close a center vent.

**Table 93. Behavioral element category means**

Behavioral element category	1	2	3	7	8	9
Task completion time (s)	2.71	3.95	5.20	3.44	5.19	5.08
Hand-off-wheel time (s)	1.74	0.13	3.35	2.24	3.99	3.12
Number of glances to IP	1.37	1.88	2.20	1.39	2.76	2.02
Av. glance to IP (s)	1.07	1.25	0.95	1.13	1.26	1.15
Total glance to IP (s)	1.45	2.20	2.01	1.59	3.08	2.36
Av. glance to roadway (s)	0.38	0.56	1.00	0.82	0.46	0.95
Av. transition time (s)	0.11	0.079	0.11	0.12	0.11	0.11

Behavioral element category	10	11	12	13	14	15
Task completion time (s)	8.41	6.52	4.85	3.91	3.44	13.33
Hand-off-wheel time (s)	7.85	5.09	3.61	3.02	n.a.	n.a.
Number of glances to IP	4.18	3.37	2.28	1.80	1.96	5.84
Av. glance to IP (s)	1.38	1.36	1.28	1.12	1.25	1.61
Total glance to IP (s)	5.39	4.12	2.83	1.98	2.49	9.37
Av. glance to roadway (s)	0.63	0.48	0.54	0.84	0.51	0.61
Av. transition time (s)	0.12	0.10	0.12	0.11	n.a.	n.a.

MidAMT - Mid 1o3 = Tune<sub>1</sub>    TopAMT - TopMoS = Tune<sub>2</sub>

Task completion time (s)	11.80	4.94	6.85	19.22	6.17	13.05
Hand-off-wheel time (s)	9.59	2.90	6.70	15.12	2.67	12.45
Number of glances to IP	5.67	2.08	3.58	9.12	2.79	6.33
Total glance to IP (s)	7.09	2.70	4.39	11.70	3.56	8.14

**4. Manual delay** This behavioral element is intended to adjust CMD for the IP tasks which require a control to be held continuously for a period of time. For instance, when drivers are lowering a power window all the way, after an appropriate control is located and reached, it might need to be held on until the movement is completed. Such an action affects only CMD and thus increases the hand-off-wheel and task completion time. In this procedure, users enter an estimated amount of time (in seconds) that a hand is required along with an appropriate behavioral element category that precedes the manual delay.

**5/6. Selective activation (1 of N controls)** This class of IP tasks is further divided into two categories by the type of control labelling: random or unfamiliar labels (category 5) and sequential or familiar labels (category 6). Basically, drivers locate and reach a target control and make a selection from (discrete) choices that the instrument offers. In the empirical model, this class of IP tasks was categorized under either continuous control (with detent) or discrete controls, both with labelling on the control (which was considered a "discrete display").

Since the driver performance of this class of IP tasks is a function of the number of available choices, a regression formula is used for each category. For category 5 (random / unfamiliar labels), the data on tasks to select 1 of 3, 6, or 12 buttons in the Pontiac pushbutton control center (included in category 6.5 of the empirical model), were used to derive an equation (Table 85). For category 6 (sequential / familiar labels), the equation was based on the data on a consecutively numbered discrete rotary control (described under category 4.1 of the empirical model, Table 79). Note that only one selection is made in this behavioral element (issues concerning a multiple selection are discussed later).

**7-9. Gross adjustment** Data currently exist for three categories under this class of behavioral elements: (1) with continuous input and visual feedback (category 7), (2) with discrete input and visual feedback (category 8), and (3) with continuous input and auditory feedback (category 9). The adjustment process, after locating and reaching a target control, involves some type of a feedback and

thus requires more of the driver's attention than the simple manipulation under category 3 does. For this class of behavioral elements, a desired state is achieved either by a selection from more than two discrete states or by reaching an interval in the continuum, and the degree of attentional demand is less than that in the next class of behavioral elements (fine adjustment).

The behavioral element values in this class are all derived from the Hayes et al. (1988) data. Category 7 values are means for task category MGE low, i.e., a low accuracy movement of a vertical slide control with detent, while category 9 values are estimated by means for turning a rotary knob (described in category 7 on the empirical model). Means from task categories involving a low accuracy adjustment of an LED segmented bar display with rate pushbuttons, i.e., LEDC low and LEDD low, were used to obtain category 8 values.

**10-13. Fine adjustment** This class of behavioral elements requires iterations of adjustment input and feedback to achieve a desired state, which is a specific point in many discrete states or in the continuum. Relative to the gross adjustment class, the attentional demand on drivers is expected to be high. Four categories for which data currently exist are: (1) with continuous input and visual feedback (category 10), (2) with discrete input and visual feedback (category 11), (3) with continuous input and tactile feedback (category 12), and (4) with discrete input and tactile feedback (category 13). As in the previous class of behavioral elements, the data from Hayes et al. (1988) were utilized.

Means from visual radio tuning tasks comprised the category 10 values. While task category Mid Tune consisted solely of "visual tuning," i.e., adjusting a rotary knob to move a horizontal pointer to a desired point, task categories Mid AMT and Top AMT included a select activation in addition to visual tuning. Since data existed for selective activation tasks which were identical to the elements in task categories Mid AMT and Top AMT, it was possible to estimate the visual tuning elements by subtracting the selective activation means (Tune<sub>1</sub> and Tune<sub>2</sub> in Table 92). Averages of task category Mid Tune and these two estimates were then entered as category 10 values.

Category 11 values were obtained from a high accuracy adjustment of an LED segmented bar display with rate pushbuttons, i.e., LEDC high and LEDD high, and adjusting a digital display with rate pushbuttons (task category Adjust Temperature, described in category 6.2 of the empirical model). Step-wise adjustments of a vertical slide control with detent, i.e., task category MGE high, and of an LED segmented bar display with rate pushbuttons, i.e., LEDC step and LEDD step, could be accomplished (1) with either a visual or tactile feedback alone, or (2) with both types of feedbacks. A general impression of this author during the data collection sessions of Hayes et al. (1988) and in the driving simulator experiments was that drivers relied more on the tactile feedback to arrive at a target setting. Hence, these task category means were used to obtain values for categories 12 and 13, respectively.

**14. Simple interpretation** Previously discussed categories of behavioral elements consisted of simple extraction of information or locating a specified target, neither of which required an interpretation of information, or adjustment of an instrument to a desired state, which required drivers only to deduce from the display the appropriate direction to move a control or the appropriate rate pushbutton to press. The cognitive demand on drivers in these categories was low. In the tasks associated with the ETAK electronic navigation aid (Table 90), on the other hand, drivers were required to examine the displayed information and to extract what they sought to know. These tasks therefore represented behavioral elements which exerted higher cognitive demands, which were considered useful in estimating the driver performance measures for future IP tasks that would involve more sophisticated functions than the existing IP tasks provided.

For this behavioral element category, means for the four tasks in the Dingus (1986) data which involved a simple interpretation of less complex information (Table 89), i.e., (1) Destination Direction, (2) Destination Distance, (3) Current Heading, and (4) Appropriate Direction, were used to obtain the category values.

**15. Complex interpretation and decision-making** Based on the performance measures and descriptions in Table 90, tasks Cross Street, Roadway Name, and Roadway Distance, from the Dingus (1986) study required a relatively complex interpretation of navigation information and warranted a separate category from the previous entry.

**IP Macroclutter** It is assumed that drivers attend to only one IP task at a time, while driving, and at this preliminary stage, the task analytic procedure does not consider possible interactions between the simultaneous operations of more than one instrument. The effect of presence of other instruments, i.e., IP macroclutter, was investigated in the second driving simulator experiment and incorporated in this procedure.

Briefly, IP macroclutter was found to affect the number of glances to IP and task completion time significantly and is thus believed to influence the complexity of an IP task. The regression equations for these dependent variables are:

$$(\text{Task completion time}) = 2.814 + 0.314 n \quad (r^2 = 0.974)$$

$$(\text{Number of glances to IP}) = 1.317 + 0.148 n \quad (r^2 = 0.951)$$

where  $n$  is the number of instruments present in the instrument panel, including the one being used for the task. These equations were used to obtain correction factors for these variables.

#### *Using the task analytic procedure*

To estimate driver IP task performance using this procedure, users need to perform a micro level analysis of a prospective task and define its behavioral elements. Since this procedure is not restricted by interface characteristics of conventional instruments, the definition of an IP task can be relatively vague as long as its behavioral objectives are clear enough to be categorized. That is, this procedure needs to know what a driver does in each task element. Users should then consult the descriptions of behavioral element categories and decide the most appropriate category for the ob-

jective of each task element. Once all task elements are assigned to one of the element categories, the task of interest can be described simply by the number of elements in each behavioral category.

After selecting the Analysis command from the Task menu, users will see the first of the two dialog boxes (Figures 93 and 94) with which to enter the results of their analysis of a prospective IP task. Users can move between the dialog boxes either by clicking the next or previous button or by pressing a carriage return or enter key. Users also move through the text entry boxes by pressing a tab key or select a specific box by placing the arrow cursor inside it and clicking the mouse button. As the number of behavioral elements are entered for each category, estimates of dependent measures and figures of merit are instantaneously updated.

When this procedure is started, all element entries are set to zero; however, the Options menu parameters are not reset and remain unchanged from the most recently entered values. Hence, unless users wish to obtain driver IP task performance estimates for a given set of behavioral element entries under different conditions, users can remain in the procedure and, for example, examine effects of some variations in the behavioral composition of the prospective task or proceed to a completely new set of element entries. Users should note that a printed copy of the current contents of the status window can be obtained by typing Command-P, without exiting the procedure. (Since the current version of IPanalyzer does not provide a printout of the behavioral element entries, users are advised to record them as they print the status window.)

#### *Validation of the task analytic procedure*

To test the accuracy of this procedure to estimate driver IP task performance, several tasks which were representative of conventional IP tasks and for which reliable experimental means were available were selected. Hayes et al. (1988) provided a limited number of "whole" tasks, which consisted of all behavioral elements in the real operation, and comparisons of actual data and task analytic estimates are illustrated below.

<b>Visual detection &amp; monitoring requiring no manual demand</b>	<input type="text" value="0"/>
<b>Check-reading (Number or label) requiring no manual demand</b>	<input type="text" value="0"/>
<b>Simple locate &amp; reach no selection involved</b>	<input type="text" value="0"/>
<b>Manual delay</b>	<input type="text" value="0"/> seconds
<b>Selective activation (1 of N choices)</b>	
<b>Random / Unfamiliar Labels: N =</b>	<input type="text" value="1"/> <input type="text" value="0"/>
<b>Sequential / Familiar Labels: N =</b>	<input type="text" value="1"/> <input type="text" value="0"/>
<b>Gross Adjustment with visual feedback... and continuous input</b>	<input type="text" value="0"/>
<b>and discrete input</b>	<input type="text" value="0"/>
<b>Gross Adjustment with auditory feedback... and continuous input</b>	<input type="text" value="0"/>
<input type="button" value="Next"/> <input type="button" value="Exit"/>	

Figure 93. Task analytic procedure dialog box (1)

<b>Fine adjustment with visual feedback... and continuous input</b>	<input type="text" value="0"/>
<b>and discrete input</b>	<input type="text" value="0"/>
<b>Fine adjustment with tactile feedback... and continuous input</b>	<input type="text" value="0"/>
<b>and discrete input</b>	<input type="text" value="0"/>
<b>Simple interpretation (visual)</b>	<input type="text" value="0"/>
<b>Complex interpretation (visual) and decision making</b>	<input type="text" value="0"/>
<b>Number of instruments in the dashboard</b>	<input type="text" value="1"/>

Figure 94. Task analytic procedure dialog box (2)

**Task category Top OTV** As described earlier in category 4.3 of the empirical model, this IP task was (1) to turn a rotary knob to power on, (2) to tune to a specified frequency with a deflection knob and a digital display, and (3) to again turn the rotary knob to adjust volume. This particular radio was the top one in the auxiliary instrument panel (Figure 9) and, for the sake of simplicity, considered as one of three instruments. A task analysis provided the set of behavioral elements (shown in Figure 95), and the driver performance estimates based on these entries were obtained (the right status window in the figure) and compared to the actual values (the left status window in the same figure).

It should be recalled that category 10 values (fine adjustment with continuous input and visual feedback) were based on means for task category Mid Tune and estimates from task categories Mid AMT and Top AMT, but not on data of this particular task category. Since the values for all three behavioral elements in this task analysis are obtained independently, this set of task analytic estimates was not recreated from the behavioral element category values which originated from the same set of data. In this perspective, the driver IP task performance estimates for this task are acceptable.

**Task category Top Time** The next example also used the top radio in the auxiliary instrument panel (Figure 9). As described in category 6.1 of the empirical model, this task involved (1) selection of 1 of 8 randomly labelled buttons of equal size and (2) check-reading of time displayed digitally (Figure 96). Once again, the element category values were independently obtained, and reasonably close estimates were provided by the task analytic procedure. (Evidently, drivers kept a hand off the steering wheel longer than estimated.)

**Task category Mid AMT** Another example of a visual radio tuning task, described earlier in category 3 of the empirical model, provided acceptable estimates (Figure 97).

<b>Task:</b>	<b>Digital OTU</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>18.19</b>
<b>Hand-Off:</b>	<b>13.34</b>
<b>Num.IPG:</b>	<b>8.75</b>
<b>Avg.IPG:</b>	<b>1.15</b>
<b>Total IPG:</b>	<b>10.10</b>
<b>Avg.DRU:</b>	<b>0.59</b>
<b>AuTrans:</b>	<b>0.11</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>90.77</b>
<b>Manual:</b>	<b>213.46</b>
<b>Overall:</b>	<b>127.58</b>
<b>Adjusted:</b>	<b>127.58</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

<b>Task:</b>	<b>Task Analysis</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>19.31</b>
<b>Hand-Off:</b>	<b>14.32</b>
<b>Num.IPG:</b>	<b>8.70</b>
<b>Avg.IPG:</b>	<b>1.16</b>
<b>Total IPG:</b>	<b>9.75</b>
<b>Avg.DRU:</b>	<b>0.86</b>
<b>AuTrans:</b>	<b>0.11</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>90.36</b>
<b>Manual:</b>	<b>229.09</b>
<b>Overall:</b>	<b>131.98</b>
<b>Adjusted:</b>	<b>131.98</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

Actual task elements:

1. Turn on with a rotary knob
2. Turn a rotary deflection knob to tune (digital display)
3. Turn the first rotary knob to adjust volume

Task analytic estimate entries:

Simple locate and reach: 1 element

Fine adjustment with visual feedback and continuous input: 1 element

Gross adjustment with auditory feedback and continuous input: 1 element

Number of instruments: 3

Figure 95. Comparison of actual data and estimates (Top OTV)

<b>Task:</b>	<b>Check Time</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>7.34</b>
<b>Hand-Off:</b>	<b>3.59</b>
<b>Num.IPG:</b>	<b>3.54</b>
<b>Aug.IPG:</b>	<b>1.40</b>
<b>Total IPG:</b>	<b>4.66</b>
<b>Aug.DRU:</b>	<b>0.45</b>
<b>AuTrans:</b>	<b>0.12</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>39.73</b>
<b>Manual:</b>	<b>57.49</b>
<b>Overall:</b>	<b>45.05</b>
<b>Adjusted:</b>	<b>45.05</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

<b>Task:</b>	<b>Task Analysis</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>7.10</b>
<b>Hand-Off:</b>	<b>1.96</b>
<b>Num.IPG:</b>	<b>3.43</b>
<b>Aug.IPG:</b>	<b>1.11</b>
<b>Total IPG:</b>	<b>3.42</b>
<b>Aug.DRU:</b>	<b>0.57</b>
<b>AuTrans:</b>	<b>0.11</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>31.33</b>
<b>Manual:</b>	<b>31.40</b>
<b>Overall:</b>	<b>31.35</b>
<b>Adjusted:</b>	<b>31.35</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

Actual task elements:

1. Press 1 of 8 randomly labelled buttons
2. Read time in a digital display

Task analytic estimate entries:

Select 1 of 8 random labels: 1 element

Check-reading: 1 element

Number of instruments: 3

Figure 96. Comparison of actual data and estimates (Top Time)

<b>Task:</b>	<b>Select &amp; Tune</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>11.80</b>
<b>Hand-Off:</b>	<b>9.59</b>
<b>Num.IPG:</b>	<b>5.67</b>
<b>Avg.IPG:</b>	<b>1.30</b>
<b>Total IPG:</b>	<b>7.09</b>
<b>Avg.DRU:</b>	<b>0.56</b>
<b>AuTrans:</b>	<b>0.12</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>57.28</b>
<b>Manual:</b>	<b>153.46</b>
<b>Overall:</b>	<b>86.13</b>
<b>Adjusted:</b>	<b>86.13</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

<b>Task:</b>	<b>Task Analysis</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>11.91</b>
<b>Hand-Off:</b>	<b>9.38</b>
<b>Num.IPG:</b>	<b>5.83</b>
<b>Avg.IPG:</b>	<b>1.21</b>
<b>Total IPG:</b>	<b>6.88</b>
<b>Avg.DRU:</b>	<b>0.68</b>
<b>AuTrans:</b>	<b>0.11</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>56.79</b>
<b>Manual:</b>	<b>150.16</b>
<b>Overall:</b>	<b>84.80</b>
<b>Adjusted:</b>	<b>84.80</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

Actual task elements:

1. Press 1 of 3 randomly labelled buttons
2. Turn a rotary knob to tune (continuous display)

Task analytic estimate entries:

- Select 1 of 8 random labels: 1 element
- Fine adjustment with visual feedback and continuous input: 1 element
- Number of instruments: 2

Figure 97. Comparison of actual data and estimates (Mid AMT)

**Telephone dialing** This procedure operates on the assumption that task elements are independent and sequential. That is, there should be no interaction between elements and no overlap between (or simultaneous operations of) elements. This assumption makes values from behavioral element categories additive and provides a conservative estimate of the driver IP task performance measures.

As demonstrated in the previous examples, when two consecutive task elements are from different behavioral categories, this assumption appears to be valid and this procedure provides reasonable performance estimates of an IP task. However, when elements from the same category are repeated, as in the case of a pushbutton telephone dialing task, this assumption results in an overly conservative estimate.

As described earlier in category 6.4 of the empirical model, the telephone dialing task involved a given number of digits to be sequentially pressed using the standard 12-key keypad. For this example, dialing a 7-digit local telephone number was entered as 7 elements of selecting 1 of 12 sequentially labelled button (Figure 98).

Clearly, this example suggests that drivers dialed more than one digit at a time and that there were significant interactions between behavioral elements. It may be more appropriate to consider this task, for example, as one element of 3 sequential selections of 12 and two elements of 2 sequential selections of 12. As reported by Rockwell (1983) and in the section for the first driving simulator experiment, the amount of time that drivers are willing to keep their eyes off the forward view, i.e., the average length of glances to IP, is dependent on the concurrent driving workload. A change in the concurrent driving workload, however, not only changes the relevant behavioral element value, but also the behavioral element category itself. That is, when the traffic density is negligible, drivers might be able to dial four digits; when the traffic is heavy, they may have only time to dial one digit at a time. This type of interaction between an external factor and behavioral element category is not considered at this preliminary stage and warrants attention.

<b>Task:</b>	<b>Push Telephone</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>7.30</b>
<b>Hand-Off:</b>	<b>5.81</b>
<b>Num.IPG:</b>	<b>3.57</b>
<b>Avg.IPG:</b>	<b>1.35</b>
<b>Total IPG:</b>	<b>4.39</b>
<b>Avg.DRU:</b>	<b>0.57</b>
<b>AuTrans:</b>	<b>0.10</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>38.54</b>
<b>Manual:</b>	<b>92.96</b>
<b>Overall:</b>	<b>54.87</b>
<b>Adjusted:</b>	<b>54.87</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

<b>Task:</b>	<b>Task Analysis</b>
<b>Age:</b>	<b>All Ages</b>
<b>Gender:</b>	<b>Both</b>
<b>Workload:</b>	<b>All Levels</b>
<b>Task Time:</b>	<b>33.80</b>
<b>Hand-Off:</b>	<b>23.72</b>
<b>Num.IPG:</b>	<b>17.38</b>
<b>Avg.IPG:</b>	<b>1.23</b>
<b>Total IPG:</b>	<b>19.33</b>
<b>Avg.DRU:</b>	<b>0.54</b>
<b>AuTrans:</b>	<b>0.11</b>
<b>Figure of Merit</b>	
<b>Visual:</b>	<b>232.42</b>
<b>Manual:</b>	<b>379.46</b>
<b>Overall:</b>	<b>276.53</b>
<b>Adjusted:</b>	<b>276.53</b>
<b>Angles off Boresight</b>	
<b>Horizontal:</b>	<b>32.63</b>
<b>Vertical:</b>	<b>32.05</b>

Actual task elements:

1. Press 1 of 12 sequentially labelled buttons
2. Repeat Step 1 6 more times to dial a 7-digit telephone number

Task analytic estimate entries:

Select 1 of 12 sequential labels: 7 element

Number of instruments: 1

Figure 98. Comparison of actual data and estimates (Telephone 7)

## CONCLUSIONS

At the conclusion of this dissertation research, three main objectives were achieved:

1. An extensive literature review of driver IP task performance studies and of data collection methodologies
2. Three experiments which (1) expanded the existing database on conventional IP task performance and (2) investigated the effects of random crosswind, IP macro- and micro- clutter and label abbreviation under the precisely controlled conditions of a driving simulator
3. A computer program to aid evaluation of automotive IP designs which consists of (1) a comprehensive database of empirical data on the driver task performance, (2) the task estimate procedure which estimates driver task performance by characterizing an IP task of interest on the basis of visual attentional demand (VAD) and concurrent manual demand (CMD), and (3) the task analytic procedure which estimates driver task performance on the basis of behavioral characteristics

Before the literature review was conducted, there were several pertinent questions to be answered:

1. What is the most appropriate (set of) dependent variable(s) to measure driver IP task performance?
2. What is the best data collection methodology to obtain the dependent measure(s)?
3. What do we know about the driver IP task performance?

A lack of consistency in dependent measures was noted, particularly among the earlier studies. It also became evident that multiple criteria to address different aspects of driver performance were most appropriate. The measures of eye movements during the operation of IP tasks, which have been used in the more recent studies, provide a useful insight to the primarily visual aspect of driving and IP task operations. Combined with the traditional response time measure, the eye

glance measures allow a quantitative evaluation of driver IP task performance. While a variety of methodologies exist to measure eye movements, with certain advantages and disadvantages, the limbus and pupil tracking using a VCR provides an ideal compromise among precision, cost, and size/weight. The data collection and analysis techniques for this approach are mature and reliable.

The important findings of the driving simulator experiments were:

1. As the strength of random crosswind increased, driving workload, and thus the average length of glances to the roadway, increased; the relative difficulty of IP tasks, as reflected by the average length of glances to IP, on the other hand, decreased.
2. The driver IP task performance data collected in the driving simulator were acceptably close to those in the in-car, on-road study.
3. IP macroclutter, represented by the number of instruments, is linearly related to the complexity of an IP task, reflected in the number of glances to IP.
4. IP microclutter, represented by the number of controls within an instrument, is linearly related to both complexity (number of glances to IP) and difficulty (average length of glances to IP) of an IP task.
5. Concise and distinct labels were more desirable as more abbreviated labels required fewer glances and were located more quickly than their fully spelled counterparts.

The evaluation program, IPanalyzer, provides a sound, albeit preliminary, platform on which to base a more comprehensive design tool with larger database for conventional IP tasks and enhanced prediction capabilities for IP tasks yet to exist. IPanalyzer, however, suffers from certain weaknesses as a design tool as it currently exists.

One characteristic, not necessarily a weakness, is the medium in which research and application sides communicate. That is, in the present form, the common “language” between researchers and designers is the seven IP task performance measures. The former group collects data in these measures and enters them “raw” to the evaluation program. The latter group then retrieves the data for a task and configuration of interest and interprets these measures to deduce certain information about the task. The advantage of this approach is that it provides complete information from research and offers end-users complete latitude in interpreting it. The disadvantage is that unless end-users share the same set of criteria, the information will not produce the same conclusion, and that novice users might not understand what these measures reflect. While the figure of merit procedure provides some limited means to help evaluate these numbers, users are given as much burden as power in using the evaluation program.

The task estimate procedure has the potential to provide accurate estimates of the driver IP task performance for IP tasks yet to exist, if the precise relationship between the constructs (i.e., VMD, in terms of complexity and difficulty of an IP task, and CMD) and actual variables (i.e., the number and average length of glances to IP, and hand-off-wheel time) were understood. Lacking that knowledge, however, the estimates are tied to the existing IP tasks which provide the benchmark values in each variable.

Similarly, the task analytic procedure is restricted by the behavioral elements for which data exist, i.e., those present in the conventional IP tasks. The way in which the behavioral elements were categorized, too, could be influenced by the structure of existing IP tasks, and there may be a completely different way to decompose and categorize a task. The validation of this procedure, which, in general, provided satisfactory results, was also based on the existing tasks, and how well it will predict an IP task yet to exist is in question.

Lastly, the current evaluation program is a “dumb” model. Apart from its limited prediction capability, the program does not have the ability to offer suggestions. To be a truly useful design tool, an ability to suggest an optimal configuration for a given task, or better yet, an ability to suggest

alternative designs of an instrument to perform the task, is desired. A task descriptive language free from conventional interface characteristics, primitive examples of which the two estimation procedures demonstrated, will be one essential component to realize such a capability.

#### Direction for future research and development

From the researcher's perspective, continuing efforts should be made (1) to expand the database on driver IP task performance, (2) to gain better understanding of the underlying mechanism in the operation of tasks, and (3) to improve modelling of driver activities for a better prediction capability. From the designer's perspective, a design tool to evaluate IP designs should be a knowledge-based system which (1) can evaluate alternative designs with a more comprehensive set of criteria, not limited to human factors concerns and (2) allows a prospective task to be defined in a less interface specific and more general language, such that (3) the program can optimize and suggest potential designs. Such a capable design tool, if ever realized, might get human factors engineers involved in the design and development; it is an exciting goal to look forward to.

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## APPENDIX A. DESCRIPTION FOR PARTICIPANTS

### Experiment 1

The purpose of the study is to evaluate the ability of drivers to perform a wide variety of instrument tasks. These tasks will include adjusting radios, entering phone numbers, selecting and actuating switches, setting indicators, and other similar operations. The data obtained will be used as a basis for developing future evaluation procedures for instrument panels.

This study is being conducted by the Vehicle Analysis and Simulation Laboratory, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061 (telephone number: 703-231-9084). The research team consists of Brian Hayes and Ko Kurokawa, who are doctoral students in Industrial Engineering and Operations Research, under the direction of Dr. Walter W. Wierwille, principal investigator and P. T. Norton Professor of Industrial Engineering and Operations Research.

In this study, you will be asked to perform specific dashboard related tasks as you drive the driving simulator. There will be an experimenter beside the driving simulator to advise you of tasks to perform; another experimenter will be seated at the simulator control console to monitor its operation.

The driving simulator will simulate the handling of a late model American automobile. It is equipped with instrumentation to monitor various aspects of driving behavior. These measuring devices do not require your attention to be diverted from driving and performing tasks. Many of the tasks which you will be asked to perform will make use of an auxiliary panel mounted to your right below the dashboard. Some tasks will also require use of a projector mounted to the left-hand side of the dashboard.

### *Session 1*

This session is intended to familiarize you with the operation of the driving simulator and the tasks which you will be asked to perform. After reading this introductory material, you will be given an informed consent form. If you understand what this experiment entails and agree to participate in it by signing the form, you will be given a vision test. We will also ask to see your driver's license and will have you fill out a brief questionnaire on your driving history. Assuming that you meet all of our standardization criteria, we will schedule you for an experimental session, a brief outline of which follows.

After you are seated in the driving simulator, you will be first asked to direct your attention to the auxiliary panel to the right and the projector to the left and to become familiar with types of tasks which you will be asked to perform. At this time, you will perform the tasks without driving the simulator. You will then be shown how to operate the driving simulator and be given several minutes to drive the simulator and to get familiarized with its handling. Basically, the simulator drives very much like an actual automobile.

Finally, you will be asked to perform these tasks while driving the simulator. You should consider driving as your primary task and perform the panel tasks only when you are able to do so. At the end of this session, we hope that you will feel comfortable with the driving simulator and the tasks.

This session will take approximately 30 minutes.

### *Session 2*

Once you are familiar with the driving simulator and the tasks, you will be asked to perform these tasks during four brief drives in the simulator. While you drive the simulator, the experimenter seated beside the driving simulator will instruct you to perform certain tasks. Once again, driving is your primary task.

The driving conditions will vary among the four drives, and you might have to pay more attention to "drive safely". This session will take approximately one hour.

### *Session 3*

You will once again be asked to perform the instrument panel tasks without driving the simulator. This session will take approximately 15 minutes.

### *Additional Information*

At any time during the study, if you no longer wish to continue, you have the right to terminate your participation; you will be compensated for the length of your participation up to that point.

The simulator is a moving device. Its motion must be stopped before you can exit. Therefore, if you wish to discontinue while a run is in progress, you can do so by pressing a button on the dashboard that will be pointed out to you. Alternatively, you can ask the experimenters to stop the motion, as they also have a button to stop the motion. Please do not leave the simulator until the experimenters have indicated that you may do so.

If you have any questions about the experiment or your rights as a participant after reading the attached informed consent form, please do not hesitate to ask. We will answer your questions honestly and as openly as possible. We ask that you do not discuss the details of this experiment with any person, particularly those who may participate, as prior knowledge of seemingly incidental facts might compromise the data. It is expected that all data will have been gathered by February 28, 1989; you may feel free to discuss the study with any persons after that time.

It is possible that driving while performing the requested tasks may at times seem difficult and that you may feel stressed. Your performance and feelings reflect the difficulty of the task and **not** your capabilities and talents. Furthermore, all data will be analyzed with anonymity, i.e., immediately upon completion of your experimental sessions, your data will be identified only by a randomly assigned serial number.

## Experiments 2 and 3

The purpose of the study is to evaluate the ability of drivers to perform a wide variety of instrument tasks. These tasks will include adjusting radios, entering phone numbers, selecting and actuating switches, setting indicators, and other similar operations. The data obtained will be used as a basis for developing future evaluation procedures for instrument panels.

This study is being conducted by the Vehicle Analysis and Simulation Laboratory, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061 (telephone number: 703-231-9084). The research team consists of Ko Kurokawa and John McFarlane, who are graduate students in Industrial Engineering and Operations Research, under the direction of Dr. Walter W. Wierwille, principal investigator and P. T. Norton Professor of Industrial Engineering and Operations Research.

In this study, you will be asked to perform specific dashboard related tasks as you drive the driving simulator. There will be an experimenter beside the driving simulator to advise you of tasks to perform; another experimenter will be seated at the simulator control console to monitor its operation.

The driving simulator will simulate the handling of a late model American automobile. It is equipped with instrumentation to monitor various aspects of driving behavior. These measuring devices do not require your attention to be diverted from driving and performing tasks. Many of the tasks which you will be asked to perform will make use of an auxiliary panel mounted to your right below the dashboard. Some tasks will also require use of a projector mounted to the left-hand side of the dashboard.

After reading this introductory material, you will be given an informed consent form. If you understand what this experiment entails and agree to participate in it by signing the form, you will be given a vision test. We will also ask to see your driver's license and will have you fill out a brief questionnaire on your driving history. Assuming that you meet all of our standardization criteria, we will schedule you for an experimental session, a brief outline of which follows.

### *Session 1*

This session is intended to familiarize you with the operation of the driving simulator and the tasks which you will be asked to perform.

After you are seated in the driving simulator, you will be first asked to direct your attention to the auxiliary panel to the right and the projector to the left and to become familiar with types of tasks which you will be asked to perform. At this time, you will perform the tasks without driving the simulator. You will then be shown how to operate the driving simulator and be given several minutes to drive the simulator and to get familiarized with its handling. Basically, the simulator drives very much like an actual automobile.

Finally, you will be asked to perform these tasks while driving the simulator. You should consider driving as your primary task and perform the panel tasks only when you are able to do so. At the end of this session, we hope that you will feel comfortable with the driving simulator and the tasks.

This session will take approximately 30 minutes.

### *Session 2*

Once you are familiar with the driving simulator and the tasks, you will be asked to perform these tasks during four brief drives in the simulator. While you drive the simulator, the experimenter seated beside the driving simulator will instruct you to perform certain tasks. Once again, driving is your primary task.

### *Additional Information*

At any time during the study, if you no longer wish to continue, you have the right to terminate your participation; you will be compensated for the length of your participation up to that point.

The simulator is a moving device. Its motion must be stopped before you can exit. Therefore, if you wish to discontinue while a run is in progress, you can do so by pressing a button on the dashboard that will be pointed out to you. Alternatively, you can ask the experimenters to stop the motion, as they also have a button to stop the motion. Please do not leave the simulator until the experimenters have indicated that you may do so.

If you have any questions about the experiment or your rights as a participant after reading the attached informed consent form, please do not hesitate to ask. We will answer your questions honestly and as openly as possible. We ask that you do not discuss the details of this experiment with any person, particularly those who may participate, as prior knowledge of seemingly incidental facts might compromise the data. It is expected that all data will have been gathered by August 31, 1989; you may feel free to discuss the study with any persons after that time.

It is possible that driving while performing the requested tasks may at times seem difficult and that you may feel stressed. Your performance and feelings reflect the difficulty of the task and **not** your capabilities and talents. Furthermore, all data will be analyzed with anonymity, i.e., immediately upon completion of your experimental sessions, your data will be identified only by a randomly assigned serial number.

## APPENDIX B. PARTICIPANT'S INFORMED CONSENT

1. You are being asked to volunteer to be a participant in a research project whose purpose and description are contained in the document "Simulator Task Performance Study", which you have already read.
2. A known risk involved in this experiment includes the possibility of injury if you attempt to exit the driving simulator while it is in motion. To eliminate this risk, you agree not to attempt to leave the simulator until it has come to complete stop.
3. A potential discomfort involved in this experiment includes fatigue due to the length of the simulator driving sessions, which will last no longer than two hours in total.
4. The data gathered in this experiment will be treated with anonymity. Immediately after your participation, your name will be separated from your data.
5. While there are no direct benefits to you from this research (other than compensation), you may find the experiment interesting. Your participation, along with that of other volunteers, should make possible the improved design of instrument panels for automobiles.
6. You should not volunteer for participation in this research if you are under 18 years of age, if you do not have a valid driver's license, or if you are not in good health.
7. Please note that the principal investigator of this research project and his graduate assistants will answer any questions that you may have about this project, and you should not sign this consent form unless you are certain that you understand all of the previous descriptions and conditions.

You may also contact Dr. E. R. Stout, Chairman of the University's Institutional Review Board (telephone number: 703-231-5281), if you have questions or concerns about this experiment.

8. You may withdraw from participation at any time during the experiment without penalty. You will be compensated at the rate of \$ 5.00 per hour for the actual length of your participation.
9. Signature of the volunteer participant.

I have read and understand the details of this experiment, and I have no further questions. I hereby give my consent to participate.

---

Signature \_\_\_\_\_ Date \_\_\_\_\_

10. Signature of a member of the research team:

---

Signature \_\_\_\_\_ Date \_\_\_\_\_

APPENDIX C. QUESTIONNAIRE

4/89

We ask that you answer the following questions as thoroughly and as accurately as you can. If you feel that you can not answer a questions for any reason, simply leave it blank.

1. Age \_\_\_\_\_ Gender \_\_\_\_\_ (M or F)

2. How many years have you been driving? \_\_\_\_\_

3. Estimate the number of miles you drive each year (check the appropriate box).

- |  |   |
|--|---|
| <input type="radio"/> 0 - 2,000 miles      | <input type="radio"/> 10,000 - 14,000 miles |
| <input type="radio"/> 2,000 - 6,000 miles  | <input type="radio"/> 14,000 - 20,000 miles |
| <input type="radio"/> 6,000 - 10,000 miles | <input type="radio"/> 20,000 or more miles  |

4. Are you required to wear glasses when you drive?

Yes                      No

5. What is the make, model , and year of the car you drive most often?

Make \_\_\_\_\_

Model \_\_\_\_\_

Year \_\_\_\_\_

6. Please write two long distance (requiring area codes) telephone numbers with which you are familiar, along with the first names (or nicknames) of the persons (these will be used only during the experiment).

1. Long Distance #1 \_\_\_\_\_ Name \_\_\_\_\_

2. Long Distance #2 \_\_\_\_\_ Name \_\_\_\_\_

7. On the scale below, circle the number that best describes how susceptible you are to motion sickness.

Never get motion sick				Average				Frequently get motion sick
0	1	2	3	4	5	6		

## APPENDIX D. EXPERIMENT 1 TASK INSTRUCTIONS

### Static Run Command Set A

- **TOP Radio OFF, and center the Balance**
- **MIDDLE Radio OFF, and center the Graphic Equalizer and Balance**
- **LED must be set at the bottom and for DISCRETE mode**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

- 
1. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

---

  2. Turn the LEFT bar knob to 9.

---

  3. Increase the LED 4 steps (discrete).

---

  4. In the TOP row of the red pushbuttons, press E.

---

  5. Turn on the TOP radio, tune to 92.3 FM, and increase the volume.

---

  6. On the telephone keypad, press #, dial \_\_\_\_\_'s local number, then \*.

---

  7. On the TOP radio, press TF and read the time.

---

  8. In the LEFT column of the red pushbuttons, press D then J.

---

  9. Insert a cassette tape, side A, into the TOP radio.

---

  10. Set the LED 3 steps below the top (discrete).

---

  11. On the TOP radio, press the fast forward button.

---

  12. In the red pushbuttons, press A.

---

  13. Turn the RIGHT bar knob to 4.

---

  14. On the telephone keypad, press #, 3864 then \*.

---

  15. Of the BOTTOM 6 controls on the BOTTOM radio, press recall (RCL).

---

  16. On the MIDDLE radio, press FM/AM, then tune to 96FM.

---

  17. In the red pushbuttons, press the BOTTOM LEFT button, S.

---

  18. On the TOP radio, move the balance to the LEFT.

---

  19. Set the LED at the bottom (discrete).

---

### Change to Continuous LED Mode

20. On the TOP radio, press EJECT and place cassette on the dashboard.
21. On the TOP radio, decrease the volume.
22. In the BOTTOM row of the red pushbuttons, press R then W.
23. On the TOP radio, press AM/FM then tune to 104.5 FM.
24. Turn the RIGHT bar knob to B.
25. On the TOP radio, press the #2 button.
26. In the red pushbuttons, press H, L, then M.
27. On the BOTTOM radio, press PRESET, then increase the volume.
28. On the telephone keypad, press REDIAL.
29. On the MIDDLE radio, decrease the MIDDLE graphic equalizer 2 steps.
30. In the RIGHT column of the red pushbuttons, press C.
31. On the MIDDLE radio, move the balance to the RIGHT.
32. Set the LED 3 steps above the centerline (continuous).
33. On the TOP radio, press SEEK up.
34. Turn the LEFT bar knob to A.
35. On the BOTTOM radio, press FADE UP.
36. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.
37. Turn on the MIDDLE radio, tune to 104 FM, then increase the volume.
38. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.
39. Decrease the LED 4 steps (continuous).
40. On the MIDDLE radio, press DX/LO.
41. Set the LED to the bottom (continuous).

### Static Run Command Set B

- **TOP Radio OFF, and center the Balance**
- **MIDDLE Radio OFF, and center the Graphic Equalizer and Balance**
- **LED must be set at the bottom and for CONTINUOUS mode**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

---

1. Turn on the TOP radio, tune to 101.7 FM, then increase the volume.

---

2. On the BOTTOM radio, press AM/FM, then TUNE down.

---

3. Increase the LED 4 steps (continuous).

---

4. Insert a cassette, side A, into the TOP radio.

---

5. In the BOTTOM row of the red pushbuttons, press G.

---

6. Turn the RIGHT bar knob to 3.

---

7. In the RIGHT column of the red pushbuttons, press R then M.

---

8. Set the LED to just below the centerline (continuous).

---

9. On the TOP radio, press the #3 button.

---

10. On the BOTTOM radio, press SCAN.

---

11. Turn on the MIDDLE radio, tune to 92 FM, then increase the volume.

---

12. On the TOP radio, press the rewind button.

---

13. On the telephone keypad, press #, dial \_\_\_\_'s long distance number, then \*.

---

14. In the red pushbuttons, press the TOP LEFT button, J.

---

15. Set the LED 2 steps below the top (continuous).

---

### **Change to Discrete LED Mode**

---

16. On the MIDDLE radio, move the MIDDLE graphic equalizer to the top.

---

17. In the red pushbuttons, press A, C, then V, as in volume.

---

18. Turn the RIGHT bar knob to N.

---

19. In the TOP row of the red pushbuttons, press Q then J.

---

20. Set the LED to just below the centerline (discrete).
21. Turn the LEFT bar knob to 8.
22. On the MIDDLE radio, move the balance to the LEFT.
23. Of the LEFT 3 controls of the BOTTOM radio, press PRESET.
24. On the TOP radio, move the balance to the RIGHT.
25. Turn the LEFT bar knob to Z.
26. On the MIDDLE radio, center the MIDDLE graphic equalizer.
27. On the telephone keypad, press #, 3846, then \*.
28. On the TOP radio, press EJECT, and place cassette on the dashboard.
29. In the LEFT column of the red pushbuttons, press D.
30. Set the LED 3 steps above the bottom (discrete).
31. On the TOP radio, press SCAN.
32. On the TOP radio, press AM/FM, then tune to 104.9 FM.
33. On the TOP radio, press TF and read the time.
34. Of the BOTTOM 6 controls of the BOTTOM radio, press MUTE.
35. On the MIDDLE radio, press fast forward (EJ/FF).
36. In the red pushbuttons, press M.
37. On the telephone keypad, press #, dial \_\_\_\_'s local number, then \*.
38. Set the LED to 3 steps above the centerline (discrete).
39. On the MIDDLE radio, increase the volume.
40. On the MIDDLE radio, press FM/AM. then tune to 104 FM.
41. On the telephone keypad, press MUTE.

### Static Run Command Set C

- **TOP Radio OFF, and center the Balance**
- **MIDDLE Radio OFF, and center the Graphic Equalizer and Balance**
- **LED must be set at the bottom and for DISCRETE mode**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

- 
1. Set the LED to 3 steps above the centerline (discrete).

---

  2. Insert a cassette tape, side A, into the TOP radio.

---

  3. On the BOTTOM radio, decrease the volume, then press FADE up.

---

  4. Turn the RIGHT bar knob to X.

---

  5. In the LEFT column of the red pushbuttons, press J then S.

---

  6. On the TOP radio, press eject and place cassette on the dashboard.

---

  7. On the telephone keypad, press #, 3864, then \*.

---

  8. Set the LED at the top (discrete).

---

  9. Turn on the TOP radio, tune to 94.9 FM, then increase the volume.

---

  10. In the BOTTOM row of the red pushbuttons, press W.

---

  11. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.

---

  12. Of the BOTTOM 6 controls of the BOTTOM radio, press MUTE.

---

  13. Decrease the LED 4 steps (discrete).

### **Change to Continuous LED Mode**

- 
14. On the TOP radio, press TF, and read the time.

---

  15. In the RIGHT column of the red pushbuttons, press R.

---

  16. On the BOTTOM radio, press TUNE down.

---

  17. On the telephone keypad, press #, dial \_\_\_\_\_'s local number, then \*.

---

  18. Turn the LEFT bar knob to 7.

---

  19. On the TOP radio, move the balance to the LEFT.
-

20. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.
21. On the MIDDLE radio, move the balance to the RIGHT.
22. Of the RIGHT 3 controls on the BOTTOM radio, decrease the volume.
23. In the red pushbuttons, press H, W, then G.
24. On the MIDDLE radio, press DX/LO.
25. Decrease the LED 4 steps (continuous).
26. In the red pushbuttons, press the TOP RIGHT button, C.
27. On the TOP radio, press AM/FM, then tune to 100.3 FM.
28. In the TOP row of the red pushbuttons, press J, then C.
29. Turn the RIGHT bar knob to 2.
30. In the TOP radio, decrease the volume.
31. On the telephone keypad, press REDIAL.
32. Set the LED 2 steps above the bottom (continuous).
33. Turn the LEFT bar knob to T.
34. On the TOP radio, press the #4 button.
35. Turn on the MIDDLE radio, tune to 96FM, then increase the volume.
36. On the MIDDLE radio, increase the LEFT graphic equalizer 3 steps.
37. Set the LED at the top (continuous).
38. On the TOP radio, press fast forward.
39. On the TOP radio, press MO/ST.
40. In the red pushbuttons, press L.
41. On the MIDDLE radio, press FM/AM, then tune to 92 FM.

Practice Run Command Set

- **TOP Radio ON, and center the Balance**
- **MIDDLE Radio OFF, and center the Graphic Equalizer and Balance**
- **LED must be set at the bottom and for CONTINUOUS mode**
- **Both Rotary knobs must be set to 1**

**Crosswind (SW 3) OFF**

---

Determine your present speed.

---

Read the TOP word in the slide projector.

---

1. In the red pushbuttons, press the BOTTOM RIGHT button, R.
  2. On the TOP radio, press the #3 button.
  3. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance phone number, then \*.
  4. Set the LED 2 steps below the centerline.
- 

Read the MIDDLE word in the slide projector.

---

5. Turn the LEFT bar knob to 6.
  6. On the MIDDLE radio, move the LEFT graphic equalizer to the top.
- 

Read the BOTTOM word in the slide projector.

---

7. On the BOTTOM radio, press FADE up.
- 

**Set the Crosswind level to 2 (pot #50 0.058)**

---

8. Turn the RIGHT bar knob to 2.
  9. In the TOP row of the red pushbuttons, press Q.
  10. Increase the LED 4 steps.
- 

Read the TOP word in the slide projector.

---

11. Of the BOTTOM 6 controls on the BOTTOM radio, press recall (RCL).
- 

Determine your present speed.

---

12. On the TOP radio, press SEEK down.
- 

Read the MIDDLE word in the slide projector.

---

13. Of the RIGHT 3 controls on the BOTTOM radio, decrease the VOLUME.

---

14. On the MIDDLE radio, decrease the RIGHT graphic equalizer 2 steps.

---

15. Turn the RIGHT bar knob to X.

---

**Increase the Crosswind level to 3 (pot #50 0.117)**

---

Read the BOTTOM word in the slide projector.

---

16. decrease the LED 4 steps.

---

17. On the MIDDLE radio, center the RIGHT graphic equalizer.

---

Determine your present speed.

---

18. In the red pushbuttons, press the TOP LEFT button, J.

---

19. Of the BOTTOM 6 controls of the BOTTOM radio, press MUTE.

---

Read the TOP word in the slide projector.

---

20. On the TOP radio, press MO/ST.

---

21. Turn the LEFT bar knob to 3.

---

Read the MIDDLE word in the slide projector.

---

22. Turn the RIGHT bar knob to N.

---

**Increase the Crosswind level to 4 (pot #50 0.175)**

---

Read the BOTTOM word on the slide projector.

---

23. On the TOP radio, press the #1 button.

---

24. In the BOTTOM row of the red pushbuttons, press W.

---

25. On the BOTTOM radio, press SCAN.

---

Determine your present speed.

---

Read the TOP word in the slide projector.

---

26. Of the LEFT 3 controls of the BOTTOM radio, press PRESET.

---

27. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.

---

28. Turn the RIGHT bar knob to 3.

---

29. On the MIDDLE radio, move the MIDDLE graphic equalizer to the top.

---

30. Set the LED 2 steps below the top.

Simulator Run Command Set 1

- TOP Radio ON and in FM1 or FM2
- MIDDLE Radio OFF, and Graphic Equalizer Centered
- LED must be set at the bottom and for CONTINUOUS mode
- Both Rotary knobs must be set to 1
- Make sure that the VCR and Data Collection program are running

---

1. In the BOTTOM row of the red pushbuttons, press V, as in volume.

---

2. On the TOP radio, press the #2 button.

---

Read the TOP word in the slide projector.

---

Determine your present speed.

---

3. Turn the LEFT bar knob to 8.

---

4. Of the BOTTOM 6 controls on the BOTTOM radio, press AM/FM.

---

5. On the MIDDLE radio, move the LEFT graphic equalizer to the top.

---

Read the MIDDLE word in the slide projector.

---

6. Turn the RIGHT bar knob to B.

---

7. Increase the LED 4 steps.

---

8. On the MIDDLE radio, decrease the MIDDLE graphic equalizer 2 steps.

---

9. On the TOP radio, press SEEK up.

---

10. On the BOTTOM radio, press SCAN.

---

Read the BOTTOM word in the slide projector.

---

11. In the red pushbuttons, press the TOP RIGHT button, C.

---

12. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

---

Read the TOP word in the slide projector.

---

13. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.

---

Determine your present speed.

---

14. Set the LED 3 steps above the centerline.

---

Read the MIDDLE word in the slide projector.

15. Turn the RIGHT bar knob to 4.

Determine your present speed.

16. In the red pushbuttons, press the BOTTOM LEFT button, S.

17. Turn the RIGHT bar knob to F.

Read the BOTTOM word in the slide projector.

18. On the BOTTOM radio, increase the VOLUME.

19. On the telephone keypad, press #, dial \_\_\_\_'s long distance number, then \*.

20. In the TOP row of the red pushbuttons, press H.

Read the TOP word in the slide projector.

21. On the MIDDLE radio, move the MIDDLE graphic equalizer to the top.

22. Set the LED 2 steps below the centerline.

Read the MIDDLE word in the slide projector.

23. On the TOP radio, press MO/ST.

Determine your present speed.

24. Turn the LEFT bar knob to 2.

25. On the MIDDLE radio, center the MIDDLE graphic equalizer.

26. Of the BOTTOM 6 controls of the BOTTOM radio, press FADE up.

Read the BOTTOM word on the slide projector.

27. Increase the LED 4 steps.

28. Turn the RIGHT bar knob to 1.

29. Of the LEFT 3 controls of the BOTTOM radio, press TUNE down.

30. On the TOP radio, press the #3 button.

Read the TOP word in the slide projector.

Simulator Run Command Set 2

- **TOP Radio ON and in FM1 or FM2**
- **MIDDLE Radio OFF, and Graphic Equalizer Centered**
- **LED must be set at the bottom and for CONTINUOUS mode**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

---

1. On the MIDDLE radio, move the RIGHT graphic equalizer to the top.

---

2. Turn the RIGHT bar knob to 2.

---

3. Set the LED 2 steps below the centerline.

---

4. On the TOP radio, press SEEK up.

---

Determine your present speed.

---

Read the TOP word in the slide projector.

---

5. On the BOTTOM radio, press PRESET.

---

6. In the BOTTOM row of the red pushbuttons, press G.

---

7. On the TOP radio, press the #4 button.

---

Read the MIDDLE word in the slide projector.

---

8. Turn the LEFT bar knob to 7.

---

Read the BOTTOM word in the slide projector.

---

9. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.

---

Determine your present speed.

---

10. Of the RIGHT 3 controls on the BOTTOM radio, decrease the VOLUME.

---

11. In the red pushbuttons, press the TOP LEFT button, J.

---

Read the TOP word in the slide projector.

---

12. Turn the RIGHT bar knob to X.

---

13. On the MIDDLE radio, increase LEFT graphic equalizer 2 steps.

---

14. Of the BOTTOM 6 controls of the BOTTOM radio, press recall (RCL).

---

Read the MIDDLE word in the slide projector.

---

15. Increase the LED 4 steps.

---

Read the BOTTOM word in the slide projector.

---

16. Turn the RIGHT bar knob to 2.

---

17. On the BOTTOM radio, press FADE up.

---

Read the TOP word in the slide projector.

---

18. On the top radio, press the #1 button.

---

19. On the MIDDLE radio, center the RIGHT graphic equalizer.

---

20. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.

---

Read the MIDDLE word in the slide projector.

---

21. Turn the RIGHT bar knob to X.

---

22. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE down.

---

Read the BOTTOM word in the slide projector.

---

23. On the MIDDLE radio, move the MIDDLE graphic equalizer to the bottom.

---

Determine your present speed.

---

24. Decrease the LED 4 steps.

---

25. On the TOP radio, press SEEK down.

---

26. In the red pushbuttons, press the BOTTOM RIGHT button, R.

---

Read the TOP word in the slide projector.

---

27. Set the LED 3 steps above the centerline.

---

28. In the TOP row of the red pushbuttons, press E.

---

29. Of the LEFT 3 controls on the BOTTOM radio, press TUNE up.

---

30. Turn the LEFT bar knob to 5.

---

Determine your present speed.

### Simulator Run Command Set 3

- **TOP Radio ON and in FM1 or FM2**
- **MIDDLE Radio OFF, and Graphic Equalizer Centered**
- **LED must be set at the bottom and for CONTINUOUS mode**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

---

1. Of the **BOTTOM** 6 controls on the **BOTTOM** radio, press **SCAN**.

---

2. Turn the right bar knob to 4.

---

3. Increase the **LED** 4 steps.

---

Read the **TOP** word in the slide projector.

---

4. Set the **LED** 3 steps above the centerline.

---

5. On the **TOP** radio, press the #2 button.

---

6. Turn the left bar knob to 8.

---

Read the **MIDDLE** word in the slide projector.

---

7. On the **MIDDLE** radio, move the **RIGHT** graphic equalizer to the bottom.

---

Determine your present speed.

---

8. On the telephone keypad, press #, dial \_\_\_\_'s long distance number, then \*.

---

9. In the red pushbuttons, press the **TOP RIGHT** button, **C**.

---

10. On the **MIDDLE** radio, increase the **MIDDLE** graphic equalizer 2 steps.

---

Read the **BOTTOM** word in the slide projector.

---

11. On the **BOTTOM** radio, decrease the **VOLUME**.

---

12. On the **TOP** radio, press **MO/ST**.

---

Read the **TOP** word in the slide projector.

---

13. Turn the right bar knob to **B**.

---

Read the **MIDDLE** word in the slide projector.

---

14. In the **BOTTOM** row of the red pushbuttons, press **V**, as in volume.

---

15. Of the LEFT 3 controls on the BOTTOM radio, press PRESET.

---

Determine your present speed.

---

16. On the TOP radio, press the #3 button.

---

17. Turn the LEFT bar knob to 6.

---

18. Of the BOTTOM 6 controls of the BOTTOM radio, press FADE up.

---

Read the BOTTOM word in the slide projector.

---

19. In the red pushbuttons, press the BOTTOM LEFT button, S.

---

Determine your present speed.

---

20. On the TOP radio, press SEEK up.

---

21. Decrease the LED 4 steps.

---

Read the TOP word in the slide projector.

---

22. Turn the RIGHT bar knob to F.

---

23. Of the LEFT 3 controls on the BOTTOM radio, press TUNE down.

---

Read the MIDDLE word in the slide projector.

---

24. On the MIDDLE radio, decrease the LEFT graphic equalizer 2 steps.

---

Determine your present speed.

---

Read the BOTTOM word in the slide projector.

---

25. Turn the RIGHT bar knob to 1.

---

26. Set the LED 2 steps below the top.

---

27. On the BOTTOM radio, press MUTE.

---

28. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.

---

Read the TOP word in the slide projector.

---

29. On the MIDDLE radio, move the LEFT graphic equalizer to the top.

---

30. In the TOP row of the red pushbuttons, press Q.

---

#### Simulator Run Command Set 4

- **TOP Radio ON and in FM1 or FM2**
- **MIDDLE Radio OFF, and Graphic Equalizer Centered**
- **LED must be set at the bottom and for CONTINUOUS mode**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

---

1. Set the LED 2 steps below the centerline.

---

2. On the TOP radio, press the #4 button.

---

3. Of the RIGHT 3 controls of the BOTTOM radio, increase the VOLUME.

---

4. Turn the RIGHT bar knob to 2.

---

5. In the red pushbuttons, press the TOP LEFT button, J.

---

Read the TOP word in the slide projector.

---

6. On the TOP radio, press SEEK down.

---

Determine your present speed.

---

7. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.

---

Read the MIDDLE word in the slide projector.

---

8. On the BOTTOM radio, press TUNE up.

---

9. Turn the LEFT bar knob to 5.

---

10. On the telephone keypad, press #, dial \_\_\_\_\_'s long distance number, then \*.

---

Read the BOTTOM word in the slide projector.

---

Determine your present speed.

---

11. In the BOTTOM row of the red pushbuttons, press G.

---

Read the TOP word in the slide projector.

---

12. Increase the LED 4 steps.

---

13. Of the BOTTOM 6 controls on the BOTTOM radio, press MUTE.

---

14. Turn the RIGHT bar knob to X.

---

15. On the MIDDLE radio, increase the RIGHT graphic equalizer 2 steps.

---

Read the MIDDLE word in the slide projector.

---

16. Turn the RIGHT bar knob to N.

---

17. On the telephone keypad, press #, dial \_\_\_\_'s long distance number, then \*.

---

Read the BOTTOM word in the slide projector.

---

18. On the MIDDLE radio, move the MIDDLE graphic equalizer to the bottom.

---

19. In the TOP row of the red pushbuttons, press E.

---

20. Set the LED 3 steps below the top.

---

Read the TOP word in the slide projector.

---

Determine your present speed.

---

21. Turn the LEFT bar knob to 9.

---

22. On the TOP radio, press the #1 button.

---

23. On the BOTTOM radio, press recall (RCL).

---

Read the MIDDLE word in the slide projector.

---

24. In the red pushbuttons, press the BOTTOM RIGHT button, R.

---

Determine your present speed.

---

Read the BOTTOM word in the slide projector.

---

25. decrease the LED 4 steps.

---

26. Of the BOTTOM 6 controls of the BOTTOM radio, press FADE down.

---

27. Turn the RIGHT bar knob to 3.

---

28. On the MIDDLE radio, center the MIDDLE graphic equalizer.

---

Read the TOP word in the slide projector.

---

29. On the TOP radio, press SCAN.

---

30. Of the RIGHT 3 controls of the BOTTOM radio, press SEEK.

---

## APPENDIX E. EXPERIMENT 2 TASK INSTRUCTIONS

### Static Run Command Set 1

- **Auxiliary Panel #1 (Single)**
- **TOP Radio ON and in FM1 @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers Centered**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**

- 
1. Set the LED at the 2nd step below the centerline.
  2. Of the RIGHT 3 controls on the BOTTOM radio, decrease the VOLUME.

---

Read the TOP word in the slide projector.

- 
3. On the Auxiliary panel, press numeral 3.
  4. On the TOP radio, press AM/FM, then tune to 99.1 FM.
  5. Turn the LEFT rotary knob to 5.
  6. On the MIDDLE radio, decrease the RIGHT graphic equalizer 2 steps.
  7. Of the BOTTOM 6 controls on the BOTTOM radio, press RCL, recall.
  8. Increase the LED 4 steps.
  9. In the red pushbuttons, press the BOTTOM RIGHT button, R.

---

Read the MIDDLE word in the slide projector.

- 
10. Turn the RIGHT rotary knob to 2.
  11. On the MIDDLE radio, move the LEFT graphic equalizer to the top.
  12. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.
  13. On the TOP radio, press the #3 button.
  14. On the Auxiliary panel, press letter J.
  15. On the TOP radio, press TF and read the time.
  16. On the MIDDLE radio, press FM/AM, then tune to 96 FM.
  17. Turn the RIGHT rotary knob to X.
-

18. On the **BOTTOM** radio, press **TUNE** down.

## Static Run Command Set 2

- **Auxiliary Panel #2 (Triple)**
- **TOP Radio ON and in FM2 @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers @ BOTTOM**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**

- 
1. Of the BOTTOM 6 controls of the BOTTOM radio, press MUTE.

---

  2. Turn the RIGHT rotary knob to F.

---

  3. Set the LED at the 2nd step below the top.

---

  4. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

  5. In the Navigation control of the Auxiliary panel, press letter C.

---

  6. On the TOP radio, press #5 button.

---

  7. In the red pushbuttons, press the TOP LEFT button, J.

---

  8. On the BOTTOM radio, press FADE up.

---

Read the BOTTOM word in the slide projector.

---

9. Turn the RIGHT rotary knob to 4.

---

10. On the TOP radio, press TF and read the time.

---

11. On the MIDDLE radio, center the RIGHT graphic equalizer.

---

12. Turn the LEFT rotary knob to 2.

---

Read the TOP word in the slide projector.

---

13. In the Temperature control of the Auxiliary panel, press numeral 6.

---

14. On the MIDDLE radio, press FM/AM, then tune to 104 FM.

---

15. On the MIDDLE radio, move the MIDDLE graphic equalizer to the top.

---

16. On the TOP radio, press AM/FM, then tune to 980 AM.

---

17. Of the LEFT 3 controls of the BOTTOM radio, press PRESET.

---

18. Decrease the LED 6 steps.

Static Run Command Set 3

- **Auxiliary Panel #3 (2 x 2)**
- **TOP Radio ON and in AM @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers @ TOP**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**

- 
1. Set the LED at the 3rd step below the centerline.
  2. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.
  3. On the MIDDLE radio, press FM/AM, then tune to 100 FM.
  4. Turn the RIGHT rotary knob to B.
  5. In the Cassette control of the Auxiliary panel, press numeral 4.
  6. On the TOP radio, press TF and read the time.
  7. In the red pushbuttons, press the TOP RIGHT button, C.

---

Read the MIDDLE word in the slide projector.

- 
8. Of the BOTTOM 6 controls on the BOTTOM radio, press SCAN.
  9. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.
  10. Turn the RIGHT rotary knob to 3.
  11. On the TOP radio, press #4 button.
  12. On the TOP radio, press AM/FM, then tune to 106.1 FM.
  13. In the Radio control of the Auxiliary panel, press letter S.
  14. Turn the LEFT rotary knob to 7.

---

Read the BOTTOM word in the slide projector.

- 
15. Increase the LED 4 steps.
  16. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.
  17. On the BOTTOM radio, decrease the VOLUME.
  18. On the MIDDLE radio, increase the LEFT graphic equalizer 3 steps.

Static Run Command Set 4

- **Auxiliary Panel #4 (2 x 3)**
- **TOP Radio ON and in FM1 @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers Centered**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**

---

1. Of the LEFT 3 controls on the BOTTOM radio, press TUNE up.

---

2. Increase the LED 3 steps.

---

3. On the MIDDLE radio, press FM/AM, then tune to 92 FM.

---

4. In the Fuel Center of the Auxiliary panel, press letter E.

---

5. On the TOP radio, press TF and read the time.

---

Read the TOP word in the slide projector.

---

6. On the telephone keypad, press #, dial \_\_\_\_'s number, including the area code, then press \*.

---

7. In the red pushbuttons, press the BOTTOM LEFT button, S.

---

8. On the MIDDLE radio, move the MIDDLE graphic equalizer to the bottom.

---

9. Turn the RIGHT rotary knob to 3.

---

10. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE down.

---

11. Set the LED at the 3rd step above the centerline.

---

12. On the TOP radio, press AM/FM, then tune to 94.9 FM.

---

13. In the Communication control of the Auxiliary panel, press numeral 2.

---

14. On the TOP radio, press the #1 button.

---

15. On the MIDDLE radio, center the MIDDLE graphic equalizer.

---

16. Turn the LEFT rotary knob to 4.

---

Read the MIDDLE word in the slide projector.

---

17. On the BOTTOM radio, press AM/FM.

---

18. Turn the RIGHT rotary knob to N.

Simulator Run Command Set 1

- Auxiliary Panel #1 (Single)
- TOP Radio ON and in FM1 @ Station #1
- MIDDLE Radio @ 88 FM, and Graphic Equalizers Centered
- LED must be set at the bottom
- Both Rotary knobs must be set to 1
- Make sure that the VCR and Data Collection program are running

---

1. On the TOP radio, press the #2 button.

---

2. On the MIDDLE radio, move the RIGHT graphic equalizer to the bottom.

---

3. On the Auxiliary panel, press numeral 3.

---

4. On the MIDDLE radio, press FM/AM, then tune to 96 FM.

---

5. Of the LEFT 3 controls on the BOTTOM radio, press PRESET.

---

6. Turn the LEFT rotary knob to 6.

---

7. Set the LED at the 3rd step above the centerline.

---

8. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

Read the TOP word in the slide projector.

---

9. Turn the RIGHT rotary knob to B.

---

10. In the red pushbuttons, press the BOTTOM LEFT button, S.

---

What is your present speed?

---

11. On the MIDDLE radio, increase the MIDDLE graphic equalizer 2 steps.

---

12. On the BOTTOM radio, press TUNE up.

---

13. On the Auxiliary panel, press letter L.

---

14. On the TOP radio, press AM/FM, then tune to 104.5 FM.

---

15. Of the BOTTOM 6 controls on the BOTTOM radio, press SCAN.

---

Read the MIDDLE word in the slide projector.

---

16. On the TOP radio, press TF and read the time.

---

17. Decrease the LED 4 steps.

---

18. Turn the RIGHT rotary knob to 4.

---

What is your present speed?

---

19. Of the RIGHT 3 controls on the BOTTOM radio, increase the VOLUME.

---

20. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

Read the BOTTOM word in the slide projector.

---

21. On the TOP radio, press the #3 button.

---

22. Turn the RIGHT rotary knob to 1.

---

23. On the Auxiliary panel, press numeral 2.

---

24. On the MIDDLE radio, decrease the LEFT graphic equalizer 2 steps.

---

25. Turn the LEFT rotary knob to 4.

---

26. Set the LED at the 2nd step below the top.

---

27. On the MIDDLE radio, press FM/AM, then tune to 104 FM.

---

28. Turn the RIGHT rotary knob to F.

---

29. On the MIDDLE radio, move the LEFT graphic equalizer to the top.

---

30. On the Auxiliary panel, press letter M.

---

31. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE up.

---

32. On the TOP radio, press AM/FM, then tune to 1460 AM.

---

33. Decrease the LED 5 steps.

---

What is your present speed?

---

34. On the BOTTOM radio, press RCL, recall.

---

Read the TOP word in the slide projector.

---

35. In the red pushbuttons, press the TOP RIGHT button, C.

---

36. On the TOP radio, press TF and read the time.

---

## Starting the CURVES

---

1. On the MIDDLE radio, center the RIGHT graphic equalizer.

---

Read the MIDDLE word in the slide projector.

---

2. In the red pushbuttons, press the TOP LEFT button, J.

---

3. Set the LED at the 2nd step below the centerline.

---

4. Turn the LEFT rotary knob to 9.

---

5. On the TOP radio, press AM/FM, then tune to 94.9 FM.

---

6. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

7. Turn the RIGHT rotary knob to X.

---

8. On the MIDDLE radio, move the MIDDLE graphic equalizer to the bottom.

---

9. On the BOTTOM radio, press FADE down.

---

10. On the MIDDLE radio, press FM/AM, then tune to 92 FM.

---

11. On the Auxiliary panel, press numeral 1.

---

12. Increase the LED 4 steps.

---

13. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

---

14. On the TOP radio, press TF and read the time.

---

Read the BOTTOM word in the slide projector.

---

15. On the Auxiliary panel, press letter J.

---

16. Of the BOTTOM 6 controls on the BOTTOM radio, press MUTE.

---

17. Turn the RIGHT rotary knob to 2.

---

18. On the TOP radio, press the #4 button.

---

What is your present speed?

---

19. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

20. Turn the LEFT rotary knob to 6.

---

21. On the BOTTOM radio, decrease the VOLUME.

---

Read the TOP word in the slide projector.

---

22. On the TOP radio, press the #1 button.
  23. Set the LED at the 3rd step below the centerline.
  24. On the Auxiliary panel, press numeral 5.
  25. On the MIDDLE radio, center the MIDDLE graphic equalizer.
  26. On the TOP radio, press TF and read the time.
- 

What is your present speed?

---

27. On the MIDDLE radio, press FM/AM, then tune to 96 FM.
  28. Of the BOTTOM 6 controls on the BOTTOM radio, press AM/FM.
  29. Turn the RIGHT rotary knob to 3.
  30. On the Auxiliary panel, press letter P.
- 

Read the MIDDLE word in the slide projector.

---

31. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.
32. On the TOP radio, press AM/FM, then tune to 99.1 FM.
33. In the red pushbuttons, press the BOTTOM RIGHT button, R.
34. Of the LEFT 3 controls on the BOTTOM radio, press TUNE down.
35. Turn the RIGHT rotary knob to N.
36. Increase the LED 6 steps.

### Simulator Run Command Set 2

- **Auxiliary Panel #2 (Triple)**
- **TOP Radio ON and in FM2 @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers Centered**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

- 
1. On the BOTTOM radio, press FADE up.

---

  2. Turn the LEFT rotary knob to 8.

---

  3. On the MIDDLE radio, press FM/AM, then tune to 96 FM.

---

  4. In the Temperature control of the Auxiliary panel, press numeral 6.

---

  5. On the MIDDLE radio, increase the RIGHT graphic equalizer 2 steps.

---

  6. Turn the RIGHT rotary knob to B.

Read the TOP word in the slide projector.

- 
7. Increase the LED 4 steps.

---

  8. On the TOP radio, press TF and read the time.

---

  9. In the red pushbuttons, press the BOTTOM LEFT button, S.

What is your present speed?

- 
10. Of the LEFT 3 controls on the BOTTOM radio, press TUNE down.

---

  11. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

  12. On the TOP radio, press #3 button.

---

  13. Turn the RIGHT rotary knob to X.

Read the MIDDLE word in the slide projector.

- 
14. On the MIDDLE radio, move the MIDDLE graphic equalizer to the bottom.

---

  15. Of the BOTTOM 6 controls on the BOTTOM radio, press MUTE.

---

  16. Set the LED at the 3rd step above the centerline.

17. In the Radio control of the Auxiliary panel, press letter W.

---

18. On the TOP radio, press AM/FM, then tune to 850 AM.

---

What is your present speed?

---

19. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

---

20. Turn the LEFT rotary knob to 5.

---

21. Set the LED at the 2nd step below the centerline.

---

22. In the Navigation control of the Auxiliary panel, press letter C.

---

23. Turn the RIGHT rotary knob to N.

---

24. On the MIDDLE radio, center the MIDDLE graphic equalizer.

---

25. Of the BOTTOM 6 controls on the BOTTOM radio, press RCL, recall.

---

26. On the TOP radio, press #2 button.

---

27. On the MIDDLE radio, press FM/AM, then tune to 88 FM.

---

What is your present speed?

---

28. In the red pushbuttons, press the TOP RIGHT button, C.

---

Read the BOTTOM word in the slide projector.

---

29. On the TOP radio, press AM/FM, then tune to 104.9 FM.

---

30. Turn the RIGHT rotary knob to 4.

---

31. Decrease the LED 4 steps.

---

32. In the Radio control of the Auxiliary panel, press numeral 2.

---

33. On the BOTTOM radio, press TUNE up.

---

Read the TOP word in the slide projector.

---

34. On the telephone keypad, press #, dial \_\_\_'s number, including the area code, then press \*.

---

35. On the TOP radio, press TF and read the time.

---

36. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.

---

## Starting the CURVES

1. On the TOP radio, press AM/FM, then tune to 99.1 FM.
2. On the MIDDLE radio, increase the LEFT graphic equalizer 2 steps.
3. Turn the RIGHT rotary knob to B.
4. On the TOP radio, press #3 button.
5. Of the LEFT 3 controls on the BOTTOM radio press PRESET.
6. In the Temperature control of the Auxiliary panel, press letter S.
7. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.
8. In the red pushbuttons, press the BOTTOM RIGHT button, R.
9. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE down.

Read the MIDDLE word in the slide projector.

10. On the MIDDLE radio, press FM/AM, then tune to 104 FM.
11. In the Navigation control of the Auxiliary panel, press numeral 4.

What is your present speed?

12. On the BOTTOM radio, press SCAN.
13. Turn the LEFT rotary knob to 7.

Read the BOTTOM word in the slide projector.

14. Set the LED at the 3rd step below the top.
15. Turn the RIGHT rotary knob to 1.
16. Decrease the LED 5 steps.
17. On the TOP radio, press TF and read the time.
18. On the MIDDLE radio, center the RIGHT graphic equalizer.

What is your present speed?

19. Turn the RIGHT rotary knob to 3.

Read the TOP word in the slide projector.

20. Of the BOTTOM 6 controls on the BOTTOM radio, press AM/FM.

---
21. On the TOP radio, press #4 button.

---
22. In the Radio control of the Auxiliary panel, press numeral 3.

---
23. Set the LED at the 2nd step below the centerline.

---
24. On the telephone keypad, press #, dial \_\_\_\_'s number, including the area code, then press \*.

---
25. Turn the LEFT rotary knob to 4.

---
26. On the MIDDLE radio, move the LEFT graphic equalizer to the top.

---
27. In the Temperature control of the Auxiliary panel, press letter F.

---

What is your present speed?

---

28. Turn the RIGHT rotary knob to X.

---
29. On the MIDDLE radio, press FM/AM, then tune to 96 FM.

---
30. In the red pushbuttons, press the TOP LEFT button, J.

---
31. On the TOP radio, press AM/FM, the tune to 1460 AM.

---

Read the MIDDLE word in the slide projector.

---

32. On the BOTTOM radio, press FADE up.

---
33. On the TOP radio, press TF and read the time.

---
34. Increase the LED 4 steps.

---
35. On the MIDDLE radio, decrease the LEFT graphic equalizer 2 steps.

---
36. Of the RIGHT 3 controls on the BOTTOM radio, increase the VOLUME.

---

Simulator Run Command Set 3

- **Auxiliary Panel #3 (2 x 2)**
- **TOP Radio ON and in AM @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers Centered**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

- 
1. Increase the LED 7 steps.

---

  2. On the MIDDLE radio, press FM/AM, then tune to 100 FM.

---

  3. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE down.

---

  4. Turn the LEFT rotary knob to 9.

---

  5. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

What is your present speed?

- 
6. On the TOP radio, press TF and read the time.

---

  7. In the Cassette control of the Auxiliary panel, press numeral 1.

---

  8. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

Read the BOTTOM word in the slide projector.

- 
9. On the MIDDLE radio, decrease the MIDDLE graphic equalizer 3 steps.

---

  10. Turn the RIGHT rotary knob to 3.

---

  11. On the TOP radio, press AM/FM, then tune to 100.1 FM.

---

  12. On the BOTTOM radio, press SCAN.

---

  13. On the TOP radio, press #1 button.

---

  14. On the MIDDLE radio, move the LEFT graphic equalizer to the bottom.

Read the TOP word in the slide projector.

- 
15. In the Radio control of the Auxiliary panel, press letter Z.

---

  16. Turn the RIGHT rotary knob to 1.

17. Set the LED at the 3rd step below the top.

---

18. In the red pushbuttons, press the BOTTOM RIGHT button, R.

---

What is your present speed?

---

19. On the telephone keypad, press #, dial \_\_\_\_'s number, including the area code, then press \*.

---

20. On the MIDDLE radio, press FM/AM, then tune to 92 FM.

---

21. On the BOTTOM radio, increase the VOLUME.

---

22. On the MIDDLE radio, move the RIGHT graphic equalizer to the top.

---

23. On the TOP radio, press #2 button.

---

What is your present speed?

---

24. Turn the LEFT rotary knob to 3.

---

25. In the red pushbuttons, press the BOTTOM LEFT button, S.

---

26. In the Navigation control of the Auxiliary panel, press letter K.

---

27. Of the BOTTOM 6 controls on the BOTTOM radio, press RCL, recall.

---

28. Decrease the LED 3 steps.

---

Read the MIDDLE word in the slide projector.

---

29. Turn the RIGHT rotary knob to 4.

---

30. On the TOP radio, press TF and read the time.

---

31. In the Temperature control of the Auxiliary panel, press numeral 4.

---

32. Of the LEFT 3 controls on the BOTTOM radio, press TUNE up.

---

Read the BOTTOM word in the slide projector.

---

33. On the TOP radio, press AM/FM, then tune to 101.7 FM.

---

34. Turn the RIGHT rotary knob to B.

---

35. On the MIDDLE radio, center the RIGHT graphic equalizer.

---

36. Set the LED at the 3rd step above the bottom.

---

## Starting the CURVES

---

1. Of the RIGHT 3 controls on the BOTTOM radio, decrease the VOLUME.

---

2. On the MIDDLE radio, move the LEFT graphic equalizer to the top.

---

3. Turn the LEFT rotary knob to 6.

---

What is your present speed?

---

4. In the Radio control of the Auxiliary panel, press numeral 5.

---

5. On the BOTTOM radio, press FADE up.

---

Read the TOP word in the slide projector.

---

6. Turn the RIGHT rotary knob to 3.

---

7. Increase the LED 6 steps.

---

8. On the TOP radio, press AM/FM, then tune to 1010 AM.

---

9. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

10. In the Navigation control of the Auxiliary panel, press letter L.

---

11. On the MIDDLE radio, press FM/AM, then tune to 96 FM.

---

12. In the red pushbuttons, press the TOP RIGHT button, C.

---

13. On the TOP radio, press #3 button.

---

14. On the MIDDLE radio, center the MIDDLE graphic equalizer.

---

Read the MIDDLE word in the slide projector.

---

15. Set the LED at the 4th step above the centerline.

---

16. On the TOP radio, press TF and read the time.

---

17. Turn the RIGHT rotary knob to X.

---

18. Of the BOTTOM 6 controls on the BOTTOM radio, press AM/FM.

---

What is your present speed?

---

19. On the MIDDLE radio, move the MIDDLE graphic equalizer to the top.

---

20. Set the LED at the 2nd step below the top.

---

21. Of the LEFT 3 controls on the BOTTOM radio, press PRESET.

---
22. In the red pushbuttons, press the TOP LEFT button, J.

---
23. Turn the LEFT rotary knob to 3.

---
24. In the Cassette control of the Auxiliary panel, press letter P.

---
25. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---
26. On the BOTTOM radio, press TUNE down.

---
27. On the TOP radio, press #1 button.

---
28. On the MIDDLE radio, press FM/AM, then tune to 100 FM.

---

Read the BOTTOM word in the slide projector.

---

29. On the TOP radio, press TF and read the time.

---
30. Turn the RIGHT rotary knob to N.

---

What is your present speed?

---

31. On the MIDDLE radio, center the MIDDLE graphic equalizer.

---
32. In the Temperature control of the Auxiliary panel, press numeral 2.

---
33. Turn the RIGHT rotary knob to 4.

---
34. Decrease the LED 5 steps.

---

Read the TOP word in the slide projector.

---

35. Of the BOTTOM 6 controls on the BOTTOM radio, press MUTE.

---
36. On the TOP radio, press AM/FM, then tune to 95.1 FM.

---

Simulator Run Command Set 4

- **Auxiliary Panel #4 (2 x 3)**
- **TOP Radio ON and in FM1 @ Station #1**
- **MIDDLE Radio @ 88 FM, and Graphic Equalizers Centered**
- **LED must be set at the bottom**
- **Both Rotary knobs must be set to 1**
- **Make sure that the VCR and Data Collection program are running**

---

1. On the TOP radio, press AM/FM, then tune to 104.5 FM.

---

2. Turn the LEFT rotary knob to 7.

---

Read the TOP word in the slide projector.

---

3. Increase the LED 4 steps.

---

4. Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

---

5. In the Communication control of the Auxiliary panel, press letter R.

---

6. In the red pushbuttons, press the TOP RIGHT button, C.

---

7. On the TOP radio, press TF and read the time.

---

8. Of the BOTTOM 6 controls on the BOTTOM radio, press AM/FM.

---

9. Turn the RIGHT rotary knob to 3.

---

What is your present speed?

---

10. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

11. In the Temperature control of the Auxiliary panel, press numeral 1.

---

12. On the MIDDLE radio, move the RIGHT graphic equalizer to the top.

---

13. On the BOTTOM radio, decrease the VOLUME.

---

14. On the TOP radio, press the #3 button.

---

15. Set the LED at the 3rd step above the centerline.

---

Read the MIDDLE word in the slide projector.

---

16. Turn the RIGHT rotary knob to B.

---

17. On the MIDDLE radio, press FM/AM, then tune to 96 FM.

---

18. In the Radio control of the Auxiliary panel, press numeral 5.

---

19. On the MIDDLE radio, decrease the MIDDLE graphic equalizer 2 steps.

---

What is your present speed?

---

20. In the red pushbuttons, press the BOTTOM LEFT button, S.

---

21. On the MIDDLE radio, move the LEFT graphic equalizer to the top.

---

22. Turn the LEFT rotary knob to 2.

---

23. In the Navigation control of the Auxiliary panel, press letter M.

---

24. Of the LEFT 3 controls on the BOTTOM radio, press TUNE down.

---

Read the BOTTOM word in the slide projector.

---

25. On the TOP radio, press TF and read the time.

---

26. Turn the RIGHT rotary knob to 1.

---

27. On the TOP radio, press AM/FM, then tune to 1230 AM.

---

28. In the Fuel Center of the Auxiliary panel, press numeral 2.

---

29. On the MIDDLE radio, center the LEFT graphic equalizer.

---

30. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE up.

---

31. Set the LED at the 2nd step below the centerline.

---

What is your present speed?

---

32. On the MIDDLE radio, press FM/AM, then tune to 100 FM.

---

33. Turn the RIGHT rotary knob to F.

---

34. On the TOP radio, press the #5 button.

---

35. In the Cassette control of the Auxiliary panel, press letter H.

---

Read the TOP word in the slide projector.

---

36. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

37. On the BOTTOM radio, press MUTE.

---

38. Decrease the LED 5 steps.

---

Starting the CURVES

---

1. Turn the RIGHT rotary knob to N.
  2. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.
  3. On the TOP radio, press the #4 button.
- 

Read the MIDDLE word in the slide projector.

---

4. On the MIDDLE radio, center the RIGHT graphic equalizer.
  5. In the Cassette control of the Auxiliary panel, press letter K.
  6. On the BOTTOM radio, press PRESET.
- 

What is your present speed?

---

7. On the TOP radio, press AM/FM, then tune to 104.5 FM.
- 

Read the BOTTOM word in the slide projector.

---

8. Set the LED at the 2nd step below the centerline.
  9. Of the BOTTOM 6 controls on the BOTTOM radio, press RCL, recall.
  10. In the Radio control of the Auxiliary panel, press numeral 4.
  11. Increase the LED 7 steps.
- 

12. Turn the LEFT rotary knob to 6.
- 

13. On the MIDDLE radio, press FM/AM, then tune to 88 FM.
- 

14. On the TOP radio, press TF and read the time.
- 

15. In the Communication control of the Auxiliary panel, press numeral 5.
- 

16. In the red pushbuttons, press the TOP LEFT button, J.
- 

17. Turn the RIGHT rotary knob to 3.
- 

18. Of the RIGHT 3 controls on the BOTTOM radio, increase the VOLUME.
- 

19. On the MIDDLE radio, move the RIGHT graphic equalizer to the bottom.
- 

What is your present speed?

---

20. In the Navigation control of the Auxiliary panel, press letter X.

---

21. On the TOP radio, press AM/FM, then tune to 99.1 FM.

---

22. On the MIDDLE radio, move the MIDDLE graphic equalizer to the top.

---

Read the TOP word in the slide projector.

---

23. Of the LEFT 3 controls on the BOTTOM radio, press TUNE up.

---

24. On the TOP radio, press TF and read the time.

---

25. In the Fuel Center of the Auxiliary panel, press letter T.

---

What is your present speed?

---

26. Turn the LEFT rotary knob to 5.

---

27. On the TOP radio, press the #1 button.

---

28. Set the LED at the 3rd step below the centerline.

---

29. On the MIDDLE radio, press FM/AM, then tune to 104 FM.

---

30. In the red pushbuttons, press the BOTTOM RIGHT button, R.

---

31. Turn the RIGHT rotary knob to 2.

---

Read the MIDDLE word in the slide projector.

---

32. On the BOTTOM radio, press SCAN.

---

33. Increase the LED 5 steps.

---

34. On the MIDDLE radio, center the MIDDLE graphic equalizer.

---

35. In the Temperature control of the Auxiliary panel, press numeral 6.

---

36. On the telephone keypad, press #, dial \_\_\_\_\_'s number, including the area code, then press \*.

---

37. Turn the RIGHT rotary knob to X.

---

38. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE down.

---

## APPENDIX F. EXPERIMENT 3 TASK INSTRUCTIONS

### Static Run Command Set

#### **Instrument Panel Settings:**

TOP radio ON and FM1 @ Station #1  
MIDDLE radio Graphic Equalizers CENTERed  
LED @ BOTTOM  
Both Rotary knobs set to 1

- 
1.        5 1 4 7     On the touch panel press COMPUTE OPTIMUM ROUTE.

---

  2.               Of the LEFT 3 controls on the BOTTOM radio press PRESET.

---

  3.        3 2 2 5     AVERAGE MILES PER GALLON.

---

  4.               In the red pushbuttons, press the BOTTOM RIGHT button, R.

---

  5.        4 1 1 1     ACTIVATE TWILIGHT SENTINEL.

---

  6.        1 1 1 9     ELECTRONIC FREQUENCY SCAN.

---

  7.               Set the LED at the 2nd step below the centerline.

---

  8.        6 3 4 14    GLOBAL POSITIONING SYSTEM.

---

  9.               Turn the RIGHT rotary knob to 3.

---

  10.      2 1 1 4     AREA TRAFFIC ADVISORY.

---

  11.             On the BOTTOM radio, press SCAN.

---

  12.      3 3 6 2     ACTIVATE HEAD-UP DISPLAY.

---

  13.             On the TOP radio, press AM/FM then tune to 100.1 FM.

---

  14.      1 2 1 11    ENGAGE DRIVE-BY-WIRE.

---

  15.             On the MIDDLE radio, move the RIGHT graphic equalizer to the bottom.
-

- 
16.      6   1   8   16    LOW TIRE PRESSURE.
- 
17.      In the BOTTOM row of the red pushbuttons, press button V.
- 
18.      4   2   1   6      COLLISION AVOIDANCE SONAR.
- 
19.      On the telephone keypad, press #, dial\_\_\_\_'s number, including 1 and the area code, then press \*.
- 
20.      2   3   2   19    REPORT SYSTEM DIAGNOSTICS.
- 
21.      Increase the LED 5 steps.
- 
22.      5   3   3   17    REAR COMPARTMENT AJAR.
- 
23.      On the TOP radio, press the #4 button.
- 
24.      6   2   5   20    VERTICAL CLEARANCE CONTROL.
- 
25.      1   3   1   3      ADJUST SEAT POSITION.
- 
26.      Turn the LEFT rotary knob to 7.
- 
27.      3   1   3   10    ENGAGE ANTI-LOCK BRAKING SYSTEM.
- 
28.      On the MIDDLE radio increase the LEFT graphic equalizer 2 steps.
- 
29.      4   3   1   8      DISPLAY TELEPHONE DIRECTORY.
- 
30.      Of the BOTTOM 6 controls on the BOTTOM radio press MUTE.
- 
31.      2   2   3   12    ENGAGE FOUR-WHEEL STEERING.
- 
32.      On the TOP radio press TF and read the time.
- 
33.      5   2   2   15    LONG-RANGE NAVIGATION.
-

## Practice Run Command Set

- 
1.        3 2 5 0    ENTER PRESENT LOCATION.

---

  2.        4 3 1 0    ACTIVATE SECURITY SYSTEM.

---

  3.        In the TOP row of the red pushbuttons, press button H.

---

  4.        On the telephone keypad, press #, dial \_\_\_'s number, including 1 and the area code, then press \*.

---

  5.        5 1 3 0    ENGAGE RIDE CONTROL.

---

  6.        Turn the LEFT rotary knob to 2.

---

  7.        6 3 8 0    OUTSIDE AIR TEMPERATURE.

---

  8.        2 1 2 0    DISTANCE TO DESTINATION.

---

  9.        On the MIDDLE radio decrease the MIDDLE graphic equalizer 2 steps.

---

  10.       1 2 1 0    ACTIVATE SECURITY SYSTEM.

---

  11.       Set the LED at the 3rd step above the bottom.

---

  12.       6 1 6 0    OUTSIDE AIR TEMPERATURE.

---

  13.       On the TOP radio press AM/FM then tune to 1460 AM.

---

  14.       5 2 4 0    WEATHER ADVISORY RADIO.

---

  15.       3 3 7 0    ENTER PRESENT LOCATION.

---

  16.       On the BOTTOM radio press TUNE UP.

---

  17.       2 1 3 1    ENGAGE RIDE CONTROL.

---

## Simulator Run Command Set

### **Instrument Panel Settings:**

TOP radio ON and FM1 @ Station #1  
MIDDLE radio Graphic Equalizers CENTERed  
LED @ BOTTOM  
Both Rotary knobs set to 1

---

1.           1   3   1   7       On the touch panel press COMPUTE OPTIMUM ROUTE.

---

2.           On the TOP radio, press AM/FM, then tune to 104.5 FM.

---

3.           2   1   1   5       AVERAGE MILES PER GALLON.

---

4.           2   1   1   17      REAR COMPARTMENT AJAR.

---

5.           6   3   6   20     VERTICAL CLEARANCE CONTROL.

---

6.           On the TOP radio, press TF and read the time.

---

7.           5   2   3   2       ACTIVATE HEAD-UP DISPLAY.

---

8.           5   3   2   16     LOW TIRE PRESSURE.

---

9.           6   2   1   8       DISPLAY TELEPHONE DIRECTORY.

---

10.          3   3   4   9       ELECTRONIC FREQUENCY SCAN.

---

                                  Read the TOP word in the slide projector.

---

11.          1   2   1   11     ENGAGE DRIVE-BY-WIRE.

---

12.          4   1   1   14     GLOBAL POSITIONING SYSTEM.

---

13.          Turn the LEFT rotary knob to 6

---

14.          1   2   1   13     ESTIMATED TIME OF ARRIVAL.

---

15.          1   2   1   15     LONG-RANGE NAVIGATION.

---

16.          Increase the LED 5 steps.

---

---

17. On the MIDDLE radio, move the left graphic equalizer to the top.

---

18. 1 2 1 1      ACTIVATE TWILIGHT SENTINEL.

---

19. 6 3 5 10      ENGAGE ANTI-LOCK BRAKING SYSTEM.

---

20. 2 3 1 7      COMPUTE OPTIMUM ROUTE.

---

Read the BOTTOM word in the slide projector.

---

**Instrument Panel Settings:**

TOP radio ON and FM2 and Time

MIDDLE radio LEFT Graphic Equalizer @ TOP and the others @ CENTER

LED @ 3 steps below the centerline

LEFT Rotary knob @ 6; RIGHT Rotary knob @ 1

- 
- |     |   |   |   |    |                            |
|-----|---|---|---|----|----------------------------|
| 21. | 6 | 3 | 4 | 18 | REMAINING FUEL IN GALLONS. |
|-----|---|---|---|----|----------------------------|
- 
- |     |   |   |   |   |                       |
|-----|---|---|---|---|-----------------------|
| 22. | 3 | 2 | 5 | 3 | ADJUST SEAT POSITION. |
|-----|---|---|---|---|-----------------------|
- 
- |     |                           |  |  |  |  |
|-----|---------------------------|--|--|--|--|
| 23. | Decrease the LED 4 steps. |  |  |  |  |
|-----|---------------------------|--|--|--|--|
- 
- |     |   |   |   |   |                           |
|-----|---|---|---|---|---------------------------|
| 24. | 2 | 3 | 3 | 5 | AVERAGE MILES PER GALLON. |
|-----|---|---|---|---|---------------------------|
- 
- |     |   |   |   |    |                        |
|-----|---|---|---|----|------------------------|
| 25. | 3 | 3 | 3 | 17 | REAR COMPARTMENT AJAR. |
|-----|---|---|---|----|------------------------|
- 
- |     |   |   |   |   |                        |
|-----|---|---|---|---|------------------------|
| 26. | 6 | 3 | 8 | 4 | AREA TRAFFIC ADVISORY. |
|-----|---|---|---|---|------------------------|
- 
- |     |   |   |   |    |                                  |
|-----|---|---|---|----|----------------------------------|
| 27. | 4 | 2 | 1 | 10 | ENGAGE ANTI-LOCK BRAKING SYSTEM. |
|-----|---|---|---|----|----------------------------------|
- 
- |     |   |   |   |    |                             |
|-----|---|---|---|----|-----------------------------|
| 28. | 6 | 1 | 2 | 20 | VERTICAL CLEARANCE CONTROL. |
|-----|---|---|---|----|-----------------------------|
- 
- Read the BOTTOM word in the slide projector.
- 
- |     |   |   |   |   |                            |
|-----|---|---|---|---|----------------------------|
| 29. | 4 | 2 | 1 | 6 | COLLISION AVOIDANCE SONAR. |
|-----|---|---|---|---|----------------------------|
- 
- |     |   |   |   |    |                             |
|-----|---|---|---|----|-----------------------------|
| 30. | 4 | 3 | 1 | 12 | ENGAGE FOUR-WHEEL STEERING. |
|-----|---|---|---|----|-----------------------------|
- 
- |     |   |   |   |   |                           |
|-----|---|---|---|---|---------------------------|
| 31. | 5 | 1 | 2 | 2 | ACTIVATE HEAD-UP DISPLAY. |
|-----|---|---|---|---|---------------------------|
- 
- |     |  |  |  |  |  |
|-----|--|--|--|--|--|
| 32. | On the TOP radio, press the #2 button. |  |  |  |  |
|-----|--|--|--|--|--|
- 
- |     |   |   |   |   |                              |
|-----|---|---|---|---|------------------------------|
| 33. | 6 | 1 | 8 | 8 | DISPLAY TELEPHONE DIRECTORY. |
|-----|---|---|---|---|------------------------------|
- 
- |     |   |   |   |    |                    |
|-----|---|---|---|----|--------------------|
| 34. | 6 | 2 | 9 | 16 | LOW TIRE PRESSURE. |
|-----|---|---|---|----|--------------------|
- 
- |     |   |  |  |  |  |
|-----|---|--|--|--|--|
| 35. | On the TOP radio, press TF and read the time. |  |  |  |  |
|-----|---|--|--|--|--|
- 
- |     |   |   |   |    |                             |
|-----|---|---|---|----|-----------------------------|
| 36. | 5 | 1 | 4 | 20 | VERTICAL CLEARANCE CONTROL. |
|-----|---|---|---|----|-----------------------------|
- 
- |     |   |  |  |  |  |
|-----|---|--|--|--|--|
| 37. | Of the LEFT 3 controls on the BOTTOM radio, press PRESET. |  |  |  |  |
|-----|---|--|--|--|--|
-

---

38.	1	1	1	9	ELECTRONIC FREQUENCY SCAN.
-----	---	---	---	---	----------------------------

---

39.	1	1	1	13	ESTIMATED TIME OF ARRIVAL.
-----	---	---	---	----	----------------------------

---

Read the MIDDLE word in the slide projector.

---

40.	2	3	1	11	ENGAGE DRIVE-BY-WIRE.
-----	---	---	---	----	-----------------------

---

**Instrument Panel Settings:**

TOP radio ON and FM 2 @ Station #2

MIDDLE radio LEFT Graphic Equalizer @ TOP and the others @ CENTER

LED @ 2 steps above bottom

LEFT Rotary knob @ 6; RIGHT Rotary knob @ 1

---

41. On the MIDDLE radio, move the right graphic equalizer to the bottom.

---

42. 4 1 1 18 REMAINING FUEL IN GALLONS.

---

43. 2 1 3 19 REPORT SYSTEM DIAGNOSTICS.

---

44. Of the BOTTOM 6 controls on the BOTTOM radio, press SCAN.

---

45. 4 1 1 8 DISPLAY TELEPHONE DIRECTORY.

---

46. 1 2 1 3 ADJUST SEAT POSITION.

---

47. 5 2 3 14 GLOBAL POSITIONING SYSTEM.

---

48. In the red pushbuttons, press the TOP RIGHT button, C.

---

49. 1 3 1 17 REAR COMPARTMENT AJAR.

---

50. 3 3 9 5 AVERAGE MILES PER GALLON.

---

51. 1 3 1 15 LONG-RANGE NAVIGATION.

---

Read the TOP word in the slide projector.

---

52. 6 1 1 10 ENGAGE ANTI-LOCK BRAKING SYSTEM.

---

53. 3 2 9 7 COMPUTE OPTIMUM ROUTE.

---

54. 6 3 1 6 COLLISION AVOIDANC SONAR.

---

55. Of the RIGHT 3 controls on the BOTTOM radio, increase the VOLUME.

---

56. 3 3 5 1 ACTIVATE TWILIGHT SENTINEL.

---

57. On the telephone keypad, press #, dial \_\_\_'s number, including 1 and the area code, then press \*.

---

---

58.	4	1	1	2	ACTIVATE HEAD-UP DISPLAY.
-----	---	---	---	---	---------------------------

---

59.	4	3	1	4	AREA TRAFFIC ADVISORY.
-----	---	---	---	---	------------------------

---

60.	On the TOP row of the red pushbuttons, press button Q.				
-----	--	--	--	--	--

---

**Instrument Panel Settings:**

TOP radio ON and FM 2 @ Station #2

MIDDLE radio LEFT Graphic Equalizer @ TOP; MIDDLE @ CENTER; RIGHT @ BOTTOM

LED @ 2 steps above bottom

LEFT Rotary knob @ 6; RIGHT Rotary knob @ 1

---

61.      5   2   1   8      DISPLAY TELEPHONE DIRECTORY.

---

62.      5   2   1   20      VERTICAL CLEARANCE CONTROL.

---

63.      Of the RIGHT 3 controls on the BOTTOM radio, press SEEK.

---

64.      2   2   2   9      ELECTRONIC FREQUENCY SCAN

---

Read the MIDDLE word in the slide projector.

---

65.      3   3   2   7      COMPUTE OPTIMUM ROUTE.

---

66.      Turn the RIGHT rotary knob to 4.

---

67.      6   2   7   14      GLOBAL POSITIONING SYSTEM.

---

68.      On the MIDDLE radio, decrease the middle graphic equalizer 2 steps.

---

69.      2   1   3   11      ENGAGE DRIVE-BY-WIRE.

---

70.      3   3   7   3      ADJUST SEAT POSITION.

---

71.      2   2   2   1      ACTIVATE TWILIGHT SENTINEL.

---

72.      Of the BOTTOM 6 controls on the BOTTOM radio, press MUTE.

---

73.      6   2   3   10      ENGAGE ANTI-LOCK BRAKING SYSTEM.

---

Read the BOTTOM word in the slide projector.

---

74.      On the TOP radio, press AM/FM, then tune to 1010 AM.

---

75.      1   1   1   15      LONG-RANGE NAVIGATION.

---

76.      4   3   1   16      LOW TIRE PRESSURE.

---

---

77. On the TOP radio, press the #4 button.

---

78. 1 1 1 17 REAR COMPARTMENT AJAR.

---

79. 6 2 6 4 AREA TRAFFIC ADVISORY.

---

80. Turn the RIGHT rotary knob to 2.

---

81. 3 1 5 5 AVERAGE MILES PER GALLON.

---

82. 3 2 6 13 ESTIMATED TIME OF ARRIVAL.

---

Read the TOP word in the slide projector.

---

83. 5 2 3 18 REMAINING FUEL-IN GALLONS.

---

84. 4 2 1 8 DISPLAY TELEPHONE DIRECTORY.

---

85. 4 1 1 10 ENGAGE ANTI-LOCK BRAKING SYSTEM.

---

86. 1 1 1 7 COMPUTE OPTIMUM ROUTE.

---

87. 2 1 3 3 ADJUST SEAT POSITION.

---

88. On the telephone keypad, press #, dial \_\_\_'s number, including 1 and the area code, then press \*.

---

89. 4 1 1 16 LOW TIRE PRESSURE.

---

90. 5 3 4 2 ACTIVATE HEAD-UP DISPLAY.

---

91. 2 3 3 1 ACTIVATE TWILIGHT SENTINEL.

---

92. Turn the LEFT rotary knob to 2.

---

93. 6 3 9 14 GLOBAL POSITIONING SYSTEM.

---

94. 2 3 3 17 REAR COMPARTMENT AJAR.

---

Read the TOP word in the slide projector.

---



---

113. 4 3 1 14 GLOBAL POSITIONING SYSTEM.

---

114. 4 1 1 6 COLLISION AVOIDANCE SONAR.

---

115. 4 3 1 18 REMAINING FUEL IN GALLONS.

---

116. On the MIDDLE radio, center the LEFT graphic equalizer.

---

117. 6 1 4 4 AREA TRAFFIC ADVISORY.

---

118. Set the LED at the 2nd step below the centerline.

---

119. 2 3 1 15 LONG-RANGE NAVIGATION.

---

120. 2 2 2 13 ESTIMATED TIME OF ARRIVAL.

---

### Break

---

121. 1 2 1 9 ELECTRONIC FREQUENCY SCAN.

---

What is your present speed?

---

122. 2 3 1 3 ADJUST SEAT POSITION.

---

123. 3 2 4 11 ENGAGE DRIVE-BY-WIRE.

---

124. On the BOTTOM row of red pushbuttons, press button W.

---

125. 6 3 6 2 ACTIVATE HEAD-UP DISPLAY.

---

126. 1 3 1 1 ACTIVATE TWILIGHT SENTINEL.

---

127. 3 1 1 19 REPORT SYSTEM DIAGNOSTICS.

---

128. Of the LEFT 3 controls on the BOTTOM radio, press TUNE UP.

---

129. 5 2 1 12 ENGAGE FOUR WHEEL STEERING

---

130. 6 1 7 16 LOW TIRE PRESSURE.

---

---

131.     4   3   1   20   VERTICAL CLEARANCE CONTROL.

---

Read the **BOTTOM** word in the slide projector.

---

132.     Increase the LED 6 steps.

---

133.     6   1   5   14   GLOBAL POSITIONING SYSTEM.

---

134.     5   3   2   8     DISPLAY TELEPHONE DIRECTORY

---

135.     On the MIDDLE radio, decrease the RIGHT graphic equalizer 3 steps.

---

136.     3   3   1   15   LONG-RANGE NAVIGATION.

---

137.     1   1   1   5     AVERAGE MILES PER GALLON.

---

138.     6   2   8   6     COLLISION AVOIDANCE SONAR.

---

139.     4   2   1   12   ENGAGE FOUR-WHEEL STEERING.

---

140.     1   3   1   3     ADJUST SEAT POSITION.

---

141.     4   3   1   2     ACTIVATE HEAD-UP DISPLAY.

---

MIDDLE word.

---

142.     3   2   3   19   REPORT SYSTEM DIAGNOSTICS.

---

143.     3   1   8   17   REAR COMPARTMENT AJAR.

---

144.     On the TOP radio, press TF and read the time.

---

145.     4   2   1   18   REMAINING FUEL IN GALLONS.

---

146.     In the TOP row of the red pushbuttons, press button E.

---

147.     2   2   4   7     COMPUTE OPTIMUM ROUTE.

---

148.     Decrease the LED 5 steps.

---

- 
149.     3   3   6   11   ENGAGE DRIVE-BY-WIRE
- 
150.     1   1   1   1     ACTIVATE TWILIGHT SENTINEL.
- 
151.     4   1   1   12    ENGAGE FOUR-WHEEL STEERING.
- 
152.     3   1   9   9     ELECTRONIC FREQUENCY SCAN.
- 

Present Speed?

- 
153.     5   2   3   6     COLLISION AVOIDANCE SONAR.
- 
154.     4   2   1   20    VERTICAL CLEARANCE CONTROL.
- 
155.     Turn the LEFT rotary knob to 3.
- 
156.     5   2   1   4     AREA TRAFFIC ADVISORY.
- 
157.     6   3   2   16    LOW TIRE PRESSURE.
- 
158.     6   2   4   20    VERTICAL CLEARANCE CONTROL.
- 
159.     5   3   4   14    GLOBAL POSITIONING SYSTEM.
- 

TOP word.

- 
160.     6   3   3   8     DISPLAY TELEPHONE DIRECTORY.
- 
161.     2   1   1   13    ESTIMATED TIME OF ARRIVAL.
- 
162.     In the red pushbuttons press the bottom right button R.
- 
163.     4   2   1   2     ACTIVATE HEAD-UP DISPLAY.
- 
164.     5   1   4   12    ENGAGE FOUR-WHEEL STEERING.
- 
165.     On the BOTTOM radio, press MUTE.
- 
166.     3   2   8   15    LONG-RANGE NAVIGATION.
-

---

Present speed?

---

167. 5 3 2 4 AREA TRAFFIC ADVISORY.
- 
168. 2 3 3 9 ELECTRONIC FREQUENCY SCAN.
- 
169. 1 3 1 19 REPORT SYSTEM DIAGNOSTICS.
- 
170. On the BOTTOM row of the red pushbuttons, press button G.
- 
171. 3 2 7 5 AVERAGE MILES PER GALLON.
- 
172. 3 1 3 3 ADJUST SEAT POSITION.
- 
173. 6 1 3 12 ENGAGE FOUR-WHEEL STEERING.
- 
174. 3 1 2 11 ENGAGE DRIVE-BY-WIRE.
- 
175. On the BOTTOM radio, press SEEK.
- 
176. 4 1 1 20 VERTICAL CLEARANCE CONTROL.
- 
177. 4 3 1 10 ENGAGE ANTI-LOCK BRAKING SYSTEM
- 
178. 4 2 1 4 AREA TRAFFIC ADVISORY
- 
179. Set the LED at the 2nd step below the top.
- 

TOP word

---

182. 2 1 3 7 COMPUTE OPTIMUM ROUTE.
- 
183. 6 1 2 2 ACTIVATE HEAD-UP DISPLAY.
- 
184. On the BOTTOM radio, press RCL, Recall.
-

---

185. 1 3 1 13 ESTIMATED TIME OF ARRIVAL.

---

186. On the TOP radio, press the #1 button.

---

187. 3 1 1 1 ACTIVATE TWILIGHT SENTINEL.

---

188. 2 1 3 15 LONG-RANGE NAVIGATION.

---

189. 1 1 1 11 ENGAGE DRIVE-BY-WIRE.

---

190. 5 3 2 12 ENGAGE FOUR-WHEEL STEERING.

---

TOP word.

---

191. 5 3 2 20 VERTICAL CLEARANCE CONTROL.

---

192. On the TOP radio press TF, and read the time.

---

193. 1 1 1 19 REPORT SYSTEM DIAGNOSTICS.

---

194. Of the BOTTOM 6 controls on the BOTTOM radio, press AM/FM.

---

195. 5 1 2 6 COLLISION AVOIDANCE SONAR.

---

196. 6 1 9 18 REMAINING FUEL IN GALLONS.

---

197. On the telephone keypad, press #, dial \_\_\_'s number, including 1 and the area code, then press \*.

---

198. 2 2 2 17 REAR COMPARTMENT AJAR.

---

199. 2 3 1 19 REPORT SYSTEM DIAGNOSTICS.

---

MIDDLE word.

---

200. 6 2 4 2 ACTIVATE HEAD-UP DISPLAY.

---

201. 2 2 2 5 AVERAGE MILES PER GALLON.

---

202. 5 1 4 4 AREA TRAFFIC ADVISORY.

---

- 
203. Set the LED at the 3rd step above the centerline.
- 
204. 3 2 2 9 ELECTRONIC FREQUENCY SCAN.
- 
205. 3 3 5 19 REPORT SYSTEM DIAGNOSTICS.
- 
206. 1 1 1 3 ADJUST SEAT POSITION.
- 
- BOTTOM word.
- 
207. 1 2 1 17 REAR COMPARTMENT AJAR.
- 
208. 3 1 6 15 LONG RANGE NAVIGATION.
- 
209. 1 3 1 11 ENGAGE DRIVE-BY-WIRE.
- 
210. On the TOP radio, press the #2 button.
- 
211. 4 2 1 14 GLOBAL POSITIONING SYSTEM.
- 
212. On the MIDDLE radio, increase the LEFT graphic equalizer 2 steps.
- 
213. 5 2 3 10 ENGAGE ANTI-LOCK BRAKING SYSTEM.
- 
214. 6 2 2 18 REMAINING FUEL IN GALLONS.
- 
215. Turn the RIGHT rotary knob to 4.
- 
216. 3 3 8 13 ESTIMATED TIME OF ARRIVAL.
- 
217. 5 1 2 10 ENGAGE ANTI-LOCK BRAKING SYSTEM.
- 
- Present speed?
- 
218. 4 3 1 8 DISPLAY TELEPHONE DIRECTORY.
- 
219. 1 3 1 9 ELECTRONIC FREQUENCY SCAN.
- 
220. Of the BOTTOM 6 controls on the BOTTOM radio, press FADE down.
-

- 
221. 5 1 2 14 GLOBAL POSITIONING SYSTEM.
- 
222. 4 2 1 16 LOW TIRE PRESSURE.
- 
223. On the TOP radio press AM/FM then tune to 99.1 FM.
- 
224. 3 1 4 13 ESTIMATED TIME OF ARRIVAL.
- 
225. 4 1 1 4 AREA TRAFFIC ADVISORY.
- 
226. 2 2 4 3 ADJUST SEAT POSITION.
- 
227. On the MIDDLE radio, move the right graphic equalizer to the bottom.
- 
228. 6 1 6 6 COLLISION AVOIDANCE SONAR.
- 
229. 1 2 1 7 COMPUTE OPTIMUM ROUTE.
- 
- MIDDLE word.
- 
230. 5 1 4 8 DISPLAY TELEPHONE DIRECTORY.
- 
231. 1 2 1 5 AVERAGE MILES PER GALLON.
- 
232. In the red pushbuttons press the TOP LEFT button, J.
- 
233. 2 2 4 19 REPORT SYSTEM DIAGNOSTICS.
- 
234. 3 2 3 1 ACTIVATE TWILIGHT SENTINEL.
- 
235. 5 3 4 10 ENGAGE ANTI-LOCK BRAKING SYSTEM.
- 
236. Turn the RIGHT rotary knob to 3.
- 
237. 3 2 1 17 REAR COMPARTMENT AJAR.
- 
238. 5 3 4 18 REMAINING FUEL IN GALLONS.
- 
239. 6 2 5 12 ENGAGE FOUR-WHEEL STEERING.
-

---

Present speed?

---

240.      2   2   4   15   LONG RANGE NAVIGATION.

---

## APPENDIX G. DRIVING SIMULATOR

The driving simulator at Virginia Polytechnic Institute and State University is a versatile, closed-loop, moving-base device. It has been used for numerous research studies involving effects of various parameters on driver control, effects of fatigue, effects of physical motion, driver workload, and evaluation of new techniques in automotive technology.

The simulator provides the driver with a closed-loop roadway display in coordination with motions of yaw, roll, and lateral and longitudinal translation. Four channels of sound along with vibration are also provided. Brief descriptions of the simulator's subsystems follow.

### Visual system

Generation of the simulated roadway image is accomplished by a special purpose computing system. The generated signals are initially displayed on the face of a cathode ray tube. A close-circuit television (CCTV) camera scan converts this image and transmits it by cable to a CCTV monitor mounted above and behind the dashboard on the simulator. A fresnel lens with an effective focal length of 50.8 cm (20.0 in), located between the monitor and the human operator, decreases the apparent roadway image proximity to the driver and enhances the illusion of distance [effective distance 10.1 m (33 ft)]. Additional realism is provided by a plexiglas windshield and a sheet metal mock-up representing a hood and fenders immediately in front of the dashboard. The field of view provided by the CCTV monitor and lens subtends 39 degrees vertically and 48 degrees horizontally. During simulation, all room lights are turned off so that only the roadway display and the illuminated speedometer are visible to the driver.

### Motion system

The simulator is composed of an upper and lower platform, three main struts, and four motion servos. The upper platform consists of a standard automotive configuration including bucket seat, dashboard (with operational speedometer), steering wheel, brake and accelerator pedal, and the visual display equipment described above. The steering system is active and can be adjusted to match the characteristics of most production cars. The upper platform is pivoted at each end which permits roll motion about an axis 33.0 cm (13 in) from the upper platform floor. The roll motion is accomplished by the roll servo which is attached between the upper and lower platforms. The lower platform, while providing support for the upper platform, is supported by nine precision rubber-wheeled castors which enable the platform to rotate in yaw and to translate longitudinally and laterally on a large lucite sheet. The platform motions are generated by the combined action of three servo-operated struts which have one end pivoted about a floor-anchored support. Two of the servos are aligned with the longitudinal axis of the simulator and provide longitudinal translation and rotation in yaw. The third servo is oriented laterally and provides the lateral translation. Each motion servo is monitored by a feedback potentiometer and is controlled by its own electrohydraulic valve which receives signal inputs from the analog computer. A hydraulic pump, regulated at 10.4 MPa (1500 psi), provides fluid power to the motion system. Acoustical insulation of the pump unit controls the noise level in the simulator room. A 2.5 gallon accumulator and associated valving are used to maintain constant fluid pressure at any required flow-rate. Fluid temperature is controlled by an integral refrigeration-type heat exchanger.

### Vehicle simulation

Simulation of the vehicle dynamics is performed by an EIA TR-48 computer. Driver inputs to the steering wheel, accelerator, and brake pedals are sensed by potentiometers and converted to electrical signals. These signals are the inputs to the vehicle model simulated on the computer. Outputs of the model are analog voltages of vehicle velocity, roll, yaw, lateral position, and longitudinal position, which form the signals applied to the motion servos. These signals are applied to the driver's speedometer and to the image generation circuitry which continuously adjusts the visual display characteristics (position, perspective, velocity, etc.) to correspond to the simulated vehicle state.

The vehicle model for the simulation allows for rotations in roll and yaw as well as lateral and longitudinal translation. Four separated inputs are provided; namely, steering wheel displacement, accelerator/brake displacement, aerodynamic force (wind gust), and road curvature. The model consists of a set of simultaneous time-varying differential equations relating the inputs to the vehicle motion components. This approach approximates the dynamic response of the vehicle and permits matching of the model responses of either measured full-scale responses or to responses generated by digital simulation models.

#### Stimulus generation and measures computation

The simulator is supported by three microcomputers with multipurpose interfaces. These systems allow a wide variety of stimuli to be generated and used in the simulation. They also allow the precise on-line measurement of many kinds of performance parameters. Measures are stored on disk and then later transmitted to the University's central computing facility for statistical analysis.

Both an eight-channel chart recorder (Sanborn 350) and a 14-channel instrumentation tape recorder (Honeywell 5600E) are available on a dedicated basis for the simulation. Furthermore, a variety of special purpose equipment is available including video cameras, video recorders, audio cassette recorders, physiological monitoring equipment, and a breathalyzer. This equipment can be configured in numerous ways to fit the needs of a given experiment.

VITA  
of  
Ko Kurokawa

Personal

Born January 16, 1961 in Tokyo, Japan

Education

- Ph.D., Human Factors** Department of Industrial and Systems Engineering  
Virginia Polytechnic Institute and State University, Blacksburg, Virginia  
October, 1990
- M.S., Human Factors** Department of Industrial Engineering and Operations Research  
Virginia Polytechnic Institute and State University, Blacksburg, Virginia  
September, 1988  
Thesis: *The effect of rotation on legibility of dot-matrix characters*
- B.A., Chemistry** Swarthmore College, Swarthmore, Pennsylvania  
September, 1983
- Diploma** Northfield Mount Hermon School, Northfield, Massachusetts  
June, 1980

Relevant Experience

**Graduate Research Assistant**, Vehicle Analysis and Simulation Laboratory (W. W. Wierwille, Ph.D., Director), Human Factors Engineering Center, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, May, 1988 to September, 1990

Development of General Approach to Instrument Panel Evaluation.

- Experimental design
- Software development in BASIC and Pascal
- Data collection in driving simulator and research vehicle
- Eye tracking data analysis
- Statistical analyses
- Development of computerized model
- Report preparation

**Graduate Research Assistant**, Displays and Controls Laboratory (H. L. Snyder, Ph.D., Director), Human Factors Engineering Center, Department of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, September, 1985 to March, 1988

Military Adaptation of a Commercial Item Program for a Touch Panel Evaluation Study, Phase I (September, 1985 to September, 1986)

- Photometric measurements and analyses
- Programming support in FORTRAN

- Reliability testing
- Vendor relations

Research on the Display of Information on Matrix-Addressable Displays (September, 1986 to March, 1988)

- Experimental design
- System interfacing and integration
- Software development in Pascal
- Photometric measurements and analyses
- Data collection
- Statistical analyses
- Report preparation

In addition, provided technical support for microcomputer and programming in the laboratory

**Instructor**, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, Spring quarter, 1988

Taught a graduate level course on computer programming in Pascal

**Graduate Teaching Assistant**, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, Fall semester, 1989

Assisted in an undergraduate level course in work physiology

**Teaching Assistant**, Department of Chemistry, Swarthmore College, Swarthmore, Pennsylvania, September, 1982 to May, 1983

Assisted in laboratory sections of Introductory and Organic Chemistry courses.

**Research Technician**, Research Pathology Section, Department of Pathology, American Oncologic Hospital, Fox Chase Cancer Center, Philadelphia, Pennsylvania, June, 1983 to August, 1984

#### Professional affiliations

Student Member, Human Factors Society

Student Member, Society for Information Display

Member, Alpha Pi Mu Industrial Engineering Honor Society

#### Publications

Decker, J. J., Dye, C. J., Kurokawa, K., and Lloyd, C. J. C. (1988). Effects of display failures and symbol rotation on visual search using dot-matrix symbols. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (pp. 1386 - 1390). Santa Monica, CA: Human Factors Society.

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Kurokawa, K., Decker, J. J., Kelly, P. L., and Snyder, H. L. (1988). The effects of rotation on dot-matrix characters. In *Proceedings of the Human Factors Society 32nd Annual Meeting* (pp. 1391 - 1394). Santa Monica, CA: Human Factors Society.

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Lloyd, C. J. C., Decker, J. J., Kurokawa, K., and Snyder, H. L. (1987). Effects of line and cell failures on reading and search performance using matrix-addressable displays. *Society of Information Display International Symposium Digest of Technical Papers*, XIX, 344 - 347.

A handwritten signature in black ink, appearing to read 'K. Kurokawa'. The signature is fluid and cursive, with a long horizontal stroke extending to the right.