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Heavy Vehicle Driver Workload Assessment

Task 7B: In-Cab Text Message System and Cellular Phone Use by Heavy Vehicle Drivers in a Part-Task Driving Simulator

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16. Abstract

This report contains the results of a simulator study conducted to serve as a supplement to a NHTSA heavy vehicle driver workload field study. Its purpose was the evaluation of effects of cellular phone and text message display use tasks on driver-vehicle performance. Fourteen truck drivers participated and were asked to engage in three cellular phone dialing tasks (auto-dialing; local, 7digit diahng; and long-distance dialing), two cognitive cellular phone tasks (responding to questions of a biographic nature or involving mental arithmetic), and seven CRT text message readiig tasks (tachometer checking, time checking, radio tuning, 4-line reading, auto-dial, local-dial, and long-distance dial). Driver-vehicle performance was also evaluated relative to traffic density. Results indicated that driver-vehicle performance varied with respect to each of the three kinds of in-cab tasks. Performance was also differentiated with respect to traffic density, although to a lesser extent. Of note is that the CRT reading tasks had a relatively more noticeable impact on driver-vehicle performance than did either the dialing or cognitive tasks. This report concludes with a comparison of simulator and on-the-road data collection results and prospects for future heavy vehicle driver workload assessments.

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1.0 INTRODUCTION

1.1 Background

High-technology, in-cab control and display systems are finding their way into commercial vehicles and passenger cars. With the advent of the Intelligent Transportation Systems (ITS) initiative, the proliferation of high technology, in-cab device use is expected to increase even further. Examples of such systems include the following:

- Driver information and route guidance systems
- Text displays (e.g., pick-up address, package type)
- Vehicle subsystem monitoring and warning systems (e.g., tire pressure, oil pressure, brake failure, loading shifting)
- Computerized trip recorders (e.g., automatic record of speed, RPM, stops; driver entry of fuel purchase, state-line crossings)
- Sophisticated voice communication links (e.g., cellular phone systems)
- Crash Avoidance Systems (e.g., infra-red and TV systems, perspective displays)
- Changes to existing control and display systems (e.g., head-up displays).

Many of these high technology devices may introduce subsidiary tasks which may compete with the primary task of driving. This competition is what is referred to by the phrase "driver workload". Some of these devices can probably be used concurrently with the primary driving task without competition, but others may not. It is reasonable to assume that the inventors and manufacturers of these systems intend for these systems to enhance commercial vehicle operations efficiency and effectiveness, to help the driver in doing the job at hand, and to be safe. However, without an assessment of the driver workload associated with a high technology device, the safety of the system remains largely unknown.

What is needed is a set of workload assessment techniques with which to assess the safety implications of a device from the driver's perspective. In response to this need to assess the safety implications, the National Highway Traffic Safety Administration (NHTSA) has funded research and development of a workload assessment protocol. It is intended that the research and workload assessment protocol can serve as a basis for standard practice in the field of driver human factors test and evaluation. In industry, there exist Good Laboratory Practices (GLP), Good Manufacturing Practices (GMP) and IS0 9000 standards and certification. The field of driver-oriented test and evaluation of devices also benefits from similarly promulgated “good ergonomic evaluation practices.” The workload assessment Protocol can serve as a draft for such a standard.

This report provides a supplement to the seventh in a series of tasks involving the assessment of driver workload in heavy vehicle operation associated with in-cab devices or systems. This phase of the work had as its chief objective the application of the workload assessment protocol and workload measurement system to assess two advanced technologies. The two technologies chosen were a text message display system and a cellular phone system. These two classes of technologies may reasonably be expected to be deployed together, as evidenced by commercial products that combine text displays with voice communications. They also represent a range of visual, manual, and cognitive demand. The method and results of an on-the-road study (field study), as well as a review of relevant past research, is presented in Tijerina, Kiger, Rockwell, and Tornow (1995). The objective of the study detailed in this report is provided below.

1.2 Objective

The objective of this heavy vehicle driving simulator study was to supplement the heavy vehicle field study that investigated cellular phone and text message display use on the road. To meet this goal, an experiment was designed to integrate many of the experimental design methods and procedures of the field study. However, due to limitations in the part-task simulator, it was necessary to include only a portion of the levels of independent variables examined in the more extensive field study.

The following is a list of characteristics that describe the primary similarities and differences between the simulator study and the field study:

- The simulator study complemented the field study by providing object and event detection measures that could not be systematically captured in the field.

- The simulator study provided control over road curvature and allowed for workload assessment under controlled road curvature conditions that could not be readily assessed in the field.

- The simulator study included the same text message and cellular-phone dialing and dialogue tasks (with minor modifications) and a similar radio tuning task to those included in the field study. A tachometer reading task was added for the simulator study in place of an air pressure reading task carried out in the instrumented vehicle.

- As in the field study, the simulator study included lanekeeping and speed measures that allowed for driver-vehicle performance data to be collected.

Collecting these data in both the field and simulator allowed for rough comparisons of significant effects to be made between studies. Of particular interest was whether or not similar trends found in the field study also exist in the simulator. If so, this would suggest that for this type of investigation, part-task simulators might suffice in place of the more extensive on-the-road data collection.

- The simulator cab replicated the interior of a Kenworth truck cab, not the interior of the heavy vehicle cab used in the field study. Therefore, the text display is positioned in a different location. Furthermore, a different radio and clock were installed in the simulator than those installed in the instrumented vehicle.

- The simulator scenarios could not replicate night lighting conditions. All data collected in the simulator was for simulated daylight conditions.

- The simulator did not simulate both divided and undivided road types. All scenarios incorporated a 2-lane undivided roadway.

- Traffic density in the part-task simulator involved different numbers of vehicles in the opposite direction only. There were never lead vehicles in the simulator scenarios.

- Visual, kinesthetic, and auditory cues available on the road were either absent or substantially simplified in the fixed-base part-task simulator.

2.0 APPROACH

2.1 Subjects

Fourteen male truck drivers participated in this experiment. All were Commercial Driver License (CDL) certified and had varying tractor-trailer rig experience. Each was paid $15 per hour for approximately four hours of experiment time. The mean age of the drivers was 47.1 years, while ages ranged from 26 to 68 years. The mean years CDL driving experience was 22. The mean commercial miles driven last year was 57,045 miles. Twelve of the drivers reported previous cellular-phone experience. Table 1 summarizes the subject characteristics of the drivers, grouped by age.

Table 1. Summary of Subject Characteristics, Grouped by Age

Age Group	Number in Age Group	Years with a CDL	Commercial Miles Driven Last Year
< 31 yrs	1	3.0	100,000
31-40yrs	2	9.5	85,000
41 - 50 yrs	6	22.3	61,500
51 -64yrs	4	33.0	20,000
< 69 yrs	1	20.0	10,000

2.2 Equipment: Software/Hardware

The equipment consisted of the STISIM driving simulator, truck cab mock-up, secondary task response devices, cellular-phone, dash-mounted text messaging display, and voice-mail/answering system.

2.2.1 STISIM Driving Simulator

This closed-loop, low-fidelity driving simulator was developed by Systems Technology, Inc. (STI) and consists of software and commercially available IBM PC compatible hardware components for producing visual scenes and auditory displays relevant to driving. Driver relevant truck vehicle dynamics are specified by STI. Using the scenario definition language (SDL), the user can specify scenario attributes that relate to driver psychomotor, divided attention and cognitive behavior.

The STI simulator is fully interactive and includes the following features: 5-speed automatic transmission, variable vehicle dynamics, simulated road noise (engine and drive train), tire squeal to signal loss of control on high speed turns, and wire-framed rendering of displayed objects. Major components of the system include the following: a 586-based computer that controls the simulation, a 20-inch multisynchronous monitor for the simulation display, a 14-inch EGA monitor for the experimenter, a sound blaster card, and steering, brake, and accelerator potentiometers and cables. Major capabilities of the simulator include variable length and radius curves, both expected and unexpected obstacles, a random access sound file, and a secondary visual detection task integrated into the system.

2.2.2 Truck Cab Mock-up

The truck cab mock-up was built by Daedalus, Inc. and replicates the interior of a Kenworth truck cab. The interior includes a Kenworth truck seat, steering wheel and turn-indicator assembly, and a neutral gear shift. The steering wheel is 20 inches in diameter and has been modified to accommodate two 4-way switches positioned at approximately 85 and 275 degrees. The 4-way switches are connected to the digital input ports of a Computer Dynamics CIO-D1024 card. The instrument panel on the simulator dashboard contains an operational tachometer and schematic layout of a Kenworth instrument panel. The tachometer is connected to the digital output ports of a CIO-DI024 card. Interior lights are located above each doorway, and may be adjusted to the individual needs of the driver. The rear of the truck cab is open to permit access to the simulator's two rear speakers and the air tank used to adjust the height of the driver's seat. The mock-up also has side windows on the driver and passenger doors. The driver-side door opens to allow access to the interior of the truck cab, while the passenger-side door is fixed and inoperative.

The front "windshield" of the cab is divided into two sections. The left front windshield houses a 20-inch multisync color monitor providing a simulated roadway display for the various driving scenarios. The right front windshield and the window of the driver side door are covered with black material to reduce the presence of ambient background lighting. Appendix 1 provides further details about the cab including four scanned images of the designer's blue-prints.

2.2.3 In-Cab Task Response Devices

As in the field study, verbal responses were used for most of the in-cab tasks. For example, drivers were required to read a traffic-related message on a dash-mounted text display. After it had been read aloud, a "back seat" experimenter activated a remote switch. This remote switch had two primary purposes: (1) to place a marker in the data file indicating completion of the event, and (2) to clear the text message from the display.

Two of the in-cab task events did ***not*** require a driver's verbal response: (1) the tachometer task and (2) the object detection task. To respond to the tachometer task, initiated by a text message, drivers used a 4-way switch positioned at approximately 275 degrees on the steering wheel. To permit four-way responses, the switch moved up, right, down, and left (i.e., clockwise) for tachometer values 1, 2, 3, 4, respectively. After the driver had responded to the tachometer task, the experimenter activated the remote switch to mark the end of the event in the data file and clear the message from the text display. To respond to the object detection tasks (i.e., pedestrian crossing road), drivers pressed the horn button, located in the center of the steering wheel. For all in-cab tasks, both response and latency were recorded.

2.2.4 Cellular-Phone

The cellular phone used in this experiment was a Motorola Attache Cellular-Phone, model #TX400, and similar to that used in the field study.

2.2.5 Text Message Display

For the text messaging prototype, the same 7 inch diagonal VGA-compatible green-phosphor CRT used in the field study was mounted in the center, atop the dash. Characteristics of the CRT included:

- light-on-dark polarity
- maximal/optimal contrast and brightness
- hooded to protect against glare
- display characters that subtend approximately 16 to 18 arc minutes of visual angle, assuming a 32 inch to 36 inch viewing distance.

The text messages were presented by an external computer program that ran on a 586-based computer system with a digital input card to read the text message on and off signals. The messages were displayed in Courier New type font (to emulate a non-proportional spacing font) and messages were presented in mixed case. The capacity of the text message display was four lines, appropriately centered on the screen. To present messages to the driver, a program was developed to link the STI computer and the computer that controls the messages. At pre-set distances within a scenario, messages appeared. An auditory alarm (0.5 second tone) at 900.9 Hz, sounded to announce that a message had arrived at the display.

2.2.6 Voice Mail/Answering System

As part of the cellular-phone dialogue tasks, drivers dialed a number and reached a recorded message on a answering system. The voice answering system presented the driver with a set of paced questions, each followed by a seven second pause during which the driver responded to the question. The dialogue tasks were set to last about 60 seconds; all such communications ended with the recorded voice saying "Thank you. Good-bye." Both "easy" (biographic questions) and "moderate" (arithmetic questions) difficulty levels of voice message difficulty were included.

2.3 Experimental Design

As outlined in Table 2, half of the drivers received a variation of the scenario module presentation sequence. All drivers had a training-driving run and a training-cellular-phone and text message run prior to the start of the first module. At the conclusion of the fourth test module, two modified modules that include object detection secondary tasks (i.e., modules S3' and S4') were re-presented in reverse order.

Table 2. Outline of Module Presentation Sequence

Drivers	Training		Modules							
8	Driving	In-Cab Tasks	**S3**	**S4**	**N3**	01	N4	S4'	S3'	02
8	**Driving**	In-Cab Tasks	S4	S3	N4	02	N3	S3'	S4'	01

2.4 Driving Scenarios

The NHTSA heavy-vehicle driving scenario set consisted of six separate modules each approximately 100,000 feet in length. When appropriate, drivers were instructed to drive at 55 mph. As there were curves requiring reduced speed, and embedded in-cab tasks, the time length to complete each module was approximately 30 minutes. Therefore, the total time to complete the six non-practice scenarios, not including between-module time for breaks, was approximately three hours.

Table 3 shows that the modules were defined by a 2 x 2 matrix: high and low volume traffic conditions and digital input events (secondary tasks) and no digital events. The radius of curvature difficulty for all scenarios was "easy" (see below). Four of the six modules included in-cab tasks (S3, S3', S4, S4') and two modules did not (N3, N4). Note that for comparison, two additional modules (01, 02) were included that consisted of only in-cab tasks

Table 3. Matrix of Driving Scenario Modules

Radius of Curvature Difficulty	In-Cab Tasks				No In-Cab Tasks		Only In-cab Tasks	
	Heavy Traffic		Light Traffic		Heavy Traffic	Light Traffic	No Traffic	
	Without Object Detection	With Object Detection	Without Object Detection	With Object Detection			Without Object Detection	
Easy	Module s3	Module S3’	Module S4	Module S4’	Module N3	Module N4	Module 01	Module 02

and no driving. Table 4 outlines the in-cab task event sequence within each of the four modules that included in-cab tasks. The dimensions included in Tables 3 and 4 are summarized in the following subsections.

2.4.1 Curve Conditions

The “easy” curve conditions consisted of 18 curves, nine to the left and nine to the right. For each of the curves a sign indicating the direction of the curve, and an advisory speed was posted 500 feet from the on-set of the curve. The roadway curvature was l/ 1000 (1 over the radius of the curvature, l/foot) for curves that occurred at the onset of secondary task events, and range from l/600 - l/1000 for curves that did not occur with events.

In the field study, in-cab tasks were executed without precise knowledge of the current road geometry. The simulator allows more careful control of this variable. Since a simulator pilot study showed that driver workload was greater for heavy traffic on hard curves, where possible when an in-cab task was presented more than once, both straight and curved roadways were used. If there is no difference between performance on straight versus easy curves, nothing is lost by this manipulation. However, if there should be a difference, it is important that the experimental design allow for a test of this hypothesis.

2.4.2 In-Cab Tasks

Table 5 indicates that the in-cab tasks were divided into cellular-phone dialing tasks, cellular phone dialogue tasks, text message reading, tachometer reading, time reading, and manual radio tuning, along with object detection tasks. All but the object detection tasks were initiated by a text message.

Table 4. Order of In-Cab Task Conditions

Module S3			Module S3X			Module S4			Module S4X			01X	02X
Event	Road	Curve Direction	Event	Road	Curve Direction	Event	Road	Curve Direction	Event	Road	Curve Direction	Event	Event
Radio	Curve	Right	Moving Ped	Curve	Right	Reading	Curve	Right	Time	Curve	Left	Tach	Tach
Local/Easy	Curve	Right	Auto/Hard	Curve	Right	Auto/Hard	Curve	Right	Long/Hard	Curve	Left	Long/No	Time
Time	Curve	Left	Moving Ped	No Curve		Local/Easy	Curve	Left	Reading	Curve	Left	Reading	Tach
Tach	No Curve		Reading	Curve	Left	Reading	Curve	Left	Local/Easy	Curve	Right	Time	Long/No
Tach	Curve	Right	Local/Easy	Curve	Left	Local/Easy	Curve	Left	Local/No	Curve	Right	Long/No	Tach
Reading	Curve	Left	Reading	Curve	Right	Time	No Curve		Auto/ Easy	Curve	Left	Auto/No	Auto/No
Long/Easy	Curve	Left	Stationary Ped	No Curve		Radio	Curve	Left	Tach	Curve	Right	Radio	Reading
Radio	No Curve		Tach	Curve	Left	Tach	No Curve		Stationary Ped	No Curve		Auto	Tach
Auto/No	Curve	Left	Moving Ped	No Curve		Radio	No Curve		Moving Ped	Curve	Left	Tach	Auto
Reading	Curve	Right	Time	No Curve		Tach	Curve	Left	Moving Ped	No Curve		Tach	Local/No
Time	No Curve		Long/No	Curve	Left	Long/No	Curve	Right	Time	No Curve		Reading	Time
Local/Hard	Curve	Right	Tach	No Curve		Time	Curve	Right	Moving Ped	No Curve	Right	Radio	Long/No
			Radio	No Curve					Reading	Curve		Tach	Radio
			Local/Easy	Curve	Left				Tach	No Curve	Right	Tach	Local/No
			Radio	Curve	Left				Radio	Curve	Right	Tach	Tach
			Time	Curve	Right				Stationary Ped	Curve		Local/No	Reading
			Stationary Ped	Curve	Left				Radio	No Curve		Time	Tach
			Moving Ped	No Curve					Moving Ped	No Curve		Local/No	Radio
			Local/Easy	No Curve					Local/Easy	No Curve			

Table 5. In-Cab Task Description, with Driving Task

In-Cab Task Category	Levels of In-Cab Task	Task Frequency per Module
Cellular-Phone Dialing Tasks	Auto-Dial	1
	Local	2
	Long Distance	1
Cellular-Phone Dialogue	Low Workload Dialogue	2
	Moderate Workload Dialogue	1
	Pre-recorded Terminating Message ("You may now hang up.")	1
Text Message Reading	1-Line	8
	2-Line	2
	4-Line	2
Tachometer Reading	Follows 1-Line Message	2
Time Reading	Follows l-Line Message	2
Manual Radio Tuning	Follows 2-Line Message	2

There were three types of cellular-phone dialing tasks:

(1) auto-dial-- by pressing a "recall" (RCL) button, a memory location button (e.g., " 1 "), and the "send" button on the phone;
(2) local-- a local, 7-digit call; and
(3) long distance-- a long distance, lo-digit call.

Note that all dialing tasks concluded used with the "send" button.

There were two types of question-and-answer dialogue tasks:

(1) low (easy) workload (question-and-answer) dialogue consisting of biographic questions, and

(2) moderate workload (question-and-answer) dialogues consisting of questions that require some mental arithmetic of the subject (e.g., hours of service calculations, estimates of fuel efficiency, estimates of time or distance remaining).

In addition, some of the dialing tasks included a no-dialogue condition where the driver was not administered any workload questions. The dialogue types are detailed in Appendix 2. For all cellular-phone tasks, the text message display instructed drivers of the type of call to make. Note that for each module, there were three cellular-phone dialogue tasks that included a combination of the three dialing tasks and the two dialogue tasks (along with the no-dialogue condition). A fourth call, always with local dialing and easy dialogue, was also presented in each module. In modules $3' and S4', a object detection task occurred at the same time that the text message first appeared to initiate this fourth call.

As detailed in Appendix 3, there were three types of text message reading tasks:

(1) l-line messages,
(2) 2-line messages, and
(3) 4-line messages.

The l-line messages initiated the following secondary tasks: (1) Time reading, (2) Tachometer Checking, and (3) Cellular-Phone/Dialogue. The 2-line messages initiated the manual radio tuning tasks. The 4-line messages initiated text reading tasks.

The tachometer and time reading events were initiated by means of l-line text messages. There were two of each such events per scenario, one beginning on a curve and one on a straight road. Drivers responded to the tachometer task by pressing a switch on the left side of the steering wheel which placed an event marker in the data set. To clear the message from the screen, the experimenter activated a remote switch. This response procedure, along with instructions of this and all other secondary tasks, was outlined during the intake instruction and orientation period. As in the field study, drivers gave a verbal response to the time reading task. At the conclusion of the time reading task, the ride-along experimenter activated a switch, placing an event marker in the data set to indicate the end of the event and clearing the message from the display.

The radio tuning task was initiated by a 2-line text message. When the driver had completed the tuning task and the radio display indicated the requested frequency, the ride-along experimenter activated the remote switch. Half of the radio tuning tasks began on a curve, while the other half began on a straight segment.

2.4.3 Traffic Conditions

The high volume traffic condition consisted of 125 vehicles in the approaching lane while the low volume traffic condition included 55 vehicles in the approaching lane.

2.4.4 Object Detection

Pedestrians were presented in the last two modules of the module presentation sequence (i.e., modules $3' and $4'). In each of these modules, six pedestrians were included; four that moved across the road in front of the driver, and two that were stationary at the roadside as the driver passed. Note that two of the pedestrians appeared in concert with an in-cab task, one during the 4-line text message reading task and one during a cellular-phone task. Moving pedestrians walked across the roadway at a speed of 5 feet per second, and approached from the left and the right randomly. The stationary pedestrians also appeared randomly on the edge of the roadway on the left and right side.

2.5 Data Collected

Several dependent measures were collected during this study. The data collected by the STISIM software included, ***transient response*** and ***performance*** measures. Transient response variables reflect momentary aspects of control. Table 6 lists the seven transient measures collected for this study.

Table 6. Transient Response Measures

Vehicle curvature error with respect to the road
Subject steering wheel response
Subject throttle response
Vehicle speed
Longitudinal distance traveled
Heading error of the vehicle with respect to the road
Vehicle lane position error

Performance measures, in contrast to transient response measures, reflect longer-term performance over segments. Table 7 lists the eight performance measures collected.

Table 7. Performance Measures

Average vehicle lane position for each segment
Standard deviation of vehicle lane position error for each segment
Average vehicle speed for each segment
Standard deviation of vehicle speed for each segment
Average driver steering wheel rate for each segment
Standard deviation of driver steering wheel rate for each segment
Latency response time for divided attention task for each segment
Normalized lane exceedence distance
Peak lateral exceedence distance
Peak longitudinal lane exceedence distance

2.6 Debriefing

The final debriefing data collection was aimed at enhancing the understanding of the driving and other task strategies used by an operator during the study. At the end of the study, drivers were queried regarding driving task strategies -- the experimenters asked about strategies aimed at any unique or idiosyncratic operator performance strategies. Comments regarding the similarities between on-the-road and simulator tasks were also informally collected as part of the debriefing process.

2.7 Procedures

This section outlines general procedures used in this study. Considered in turn are outlines of the briefing, administration, and debriefing procedures.

2.7.1 Briefing

This is an initial driver orientation that was conducted prior to the start of data collection. The briefing had several purposes:

- Introduce the data collector, truck simulator, and give an overview of the general nature of the study, and
- Obtain demographic (Appendix 4) and other preliminary data, as well as obtain consent form signatures (Appendix 5).

This initial briefing was necessary to set the stage for ensuring the success of the other data collections.

2.7.2 Administration

Appendix **6** outlines the experimenter's protocol and the instructions that were read to drivers prior to the beginning of the first module.

2.7.3 Debriefing

This final data collection was aimed at insuring an understanding of the driving and other task strategies used by that operator during the study (Appendix 7). As mentioned earlier, debriefing addressed driving task strategies.

3.0 RESULTS

This section presents an overview of the results from the workload experiment conducted using the heavy-vehicle part-task driving simulator. The section is organized by the following dependent measurement categories:

- Lanekeeping
- speed
- Steering Inputs
- Object and Event Detection.

<u>Primary Tasks</u>

For each of these variables, the mean scores and standard deviations were analyzed in turn. The data for each variable were analyzed in keeping with the respective two-levels of traffic density. For further detail on the analyses conducted, refer to Appendix 8 for a listing of the ANOVA tables, and Appendix 9 for a listing of the multiple-comparison (Fisher's LSD) tables. Missing data accounted for a small portion (< 2 %) of the data. Regression analysis was used to fill in these values to complete the data set so that ***BMDP 2V, ANOVA with Repeated Measures,*** could be used. Note that where appropriate, corrected Huynh-Feldt p values are provided.

3.1 Lanekeeping Results

3.1.1 Mean Lane Position

The data for mean lane position were examined in three separate analyses. The first analysis examined the in-cab CRT text message reading tasks and an "driving-only" condition. The driving-only condition consisted of data collected from portions of the route where no secondary tasks were given and served as a baseline measure of driving. The data from this analysis are shown in Figure 1. Note that a lane position value of 0.00 corresponds to the middle of the lane, a value of 6.00 corresponds to the yellow center line (i.e., the dividing line between the two oncoming traffic lanes), and -6.00 corresponds to the far right edge of the lane. As might be expected from this figure, there was a significant effect of in-cab CRT text message reading task, $F(7,91 = 3.07$, $p < .Ol$. As outlined in Appendix 9, multiple comparisons found the time reading task to significantly differ from the radio tuning, 4-line reading, and local-dialing tasks (all p's < .05). No other differences between group events were found (all p's > .05). These results indicate that drivers kept a lane position closer to the center line for the radio tuning, 4-line reading and local-dialing tasks.

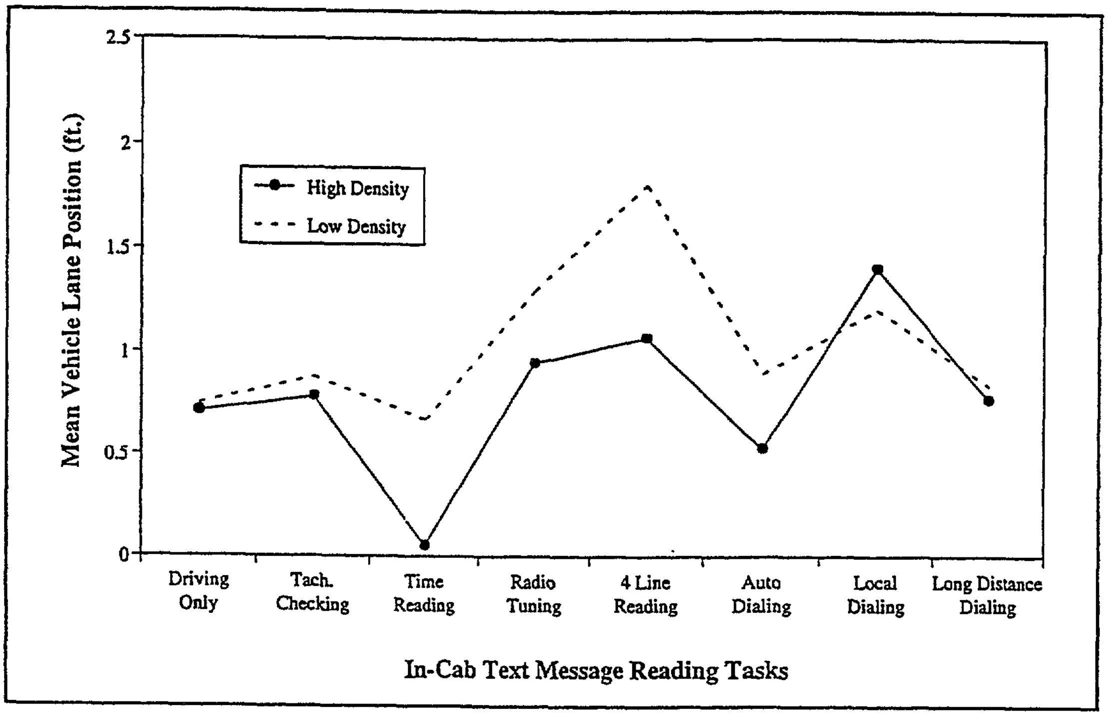


Figure 1. Mean Vehicle Lane Position as a Function of Traffic Density and In-Cab Text Message Reading Task

A second analysis of mean lane position was conducted whereby four manual task events, consisting of the three cellular-phone dialing tasks (i.e., local dialing, long-distance dialing, and automatic dialing) and the radio tuning task, and a baseline measure of driving-only, were compared. The data from this analysis are shown plotted in Figure 2. The results indicated a significant effect of traffic density, $F(l, 13) = 23.1$, $p < .OOl$, and manual task event, $F(4, 52) = 4.32$, $p < .007$. Lane position was closer to the center of the driver's lane in the high traffic density condition vs. the low traffic density condition. Multiple comparisons of the manual task conditions found the radio tuning task to be significantly different from all other conditions (all p's < .05), with a mean lane position value closest to the center line.

A third analysis using mean lane position examined the dialogue portion of the cellular phone tasks. Included in the experimental design were three types of dialogue task question sets: (1) biographic questions, (2) arithmetic questions, and (3) no questions. The biographic questions consisted of personal questions about the driver (e.g., age), while the arithmetic questions required drivers to make mental mathematical calculations. The no questions set provided an instruction to the driver to hang up the phone. In this analysis, as in the previous analysis, the three dialogue types were compared to the driving-only condition. The results of this analysis are outlined in Figure 3. A significant effect of dialogue task event was found, $F(3, 39) = 4.91$, $p < .02$. A further analysis of the dialogue events found the driving-only condition significantly different from the all three question sets (all p's < .05). This result indicates that while driving-only,. drivers were able to maintain a lane position closest to the center of their lane.

3.1.2 Lane Position Standard Deviation

The data for the standard deviations of lane position are depicted in Figure 4. A significant effect of in-cab CRT text message reading task was found, $F(7, 91) = 5.47$, $p <$,001. As might be expected, the driving-only task had the least lane position standard deviation values as compared to all other tasks (all p's < .05), except the time reading task ($p > .05$). The time reading task differed from tachometer checking, radio tuning, 4-line reading, and local-dialing tasks (all p's < .05).

A second analysis of standard deviations of lane position was conducted with the manual tasks, as outlined previously. The results are illustrated in Figure 5. Significant effects were found with traffic density, $F(1, 13) = 9.61$, $p < .008$, and manual task event, $F(4, 91) = 15.2$, $p < .OOl$. Lane deviations were less in the high traffic density condition versus the low traffic density condition. The driving-only baseline event was significantly lower than all other manual task events (all p's < .05). However, the multiple comparison tests found no significant differences between any of the manual tasks (all p's > .05).

A third analysis of standard deviations of lane position was conducted using traffic density and the dialogue task events. The data from this analysis are outlined in Figure 6. Dialogue task event proved to be significant, $F(3, 39) = 3.77$, $p < .04$. Follow-up comparisons found the driving-only condition different from the no question set ($p < .05$).

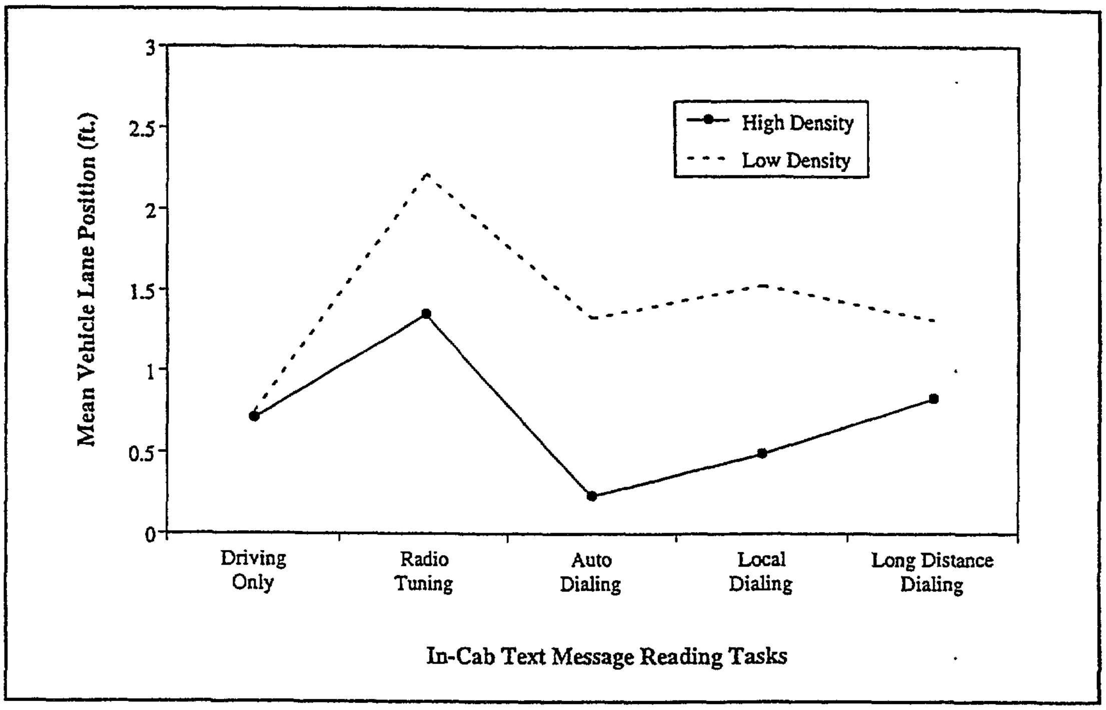


Figure 2. Mean Vehicle Lane Position as a Function of Traffic Density and Manual Task Event

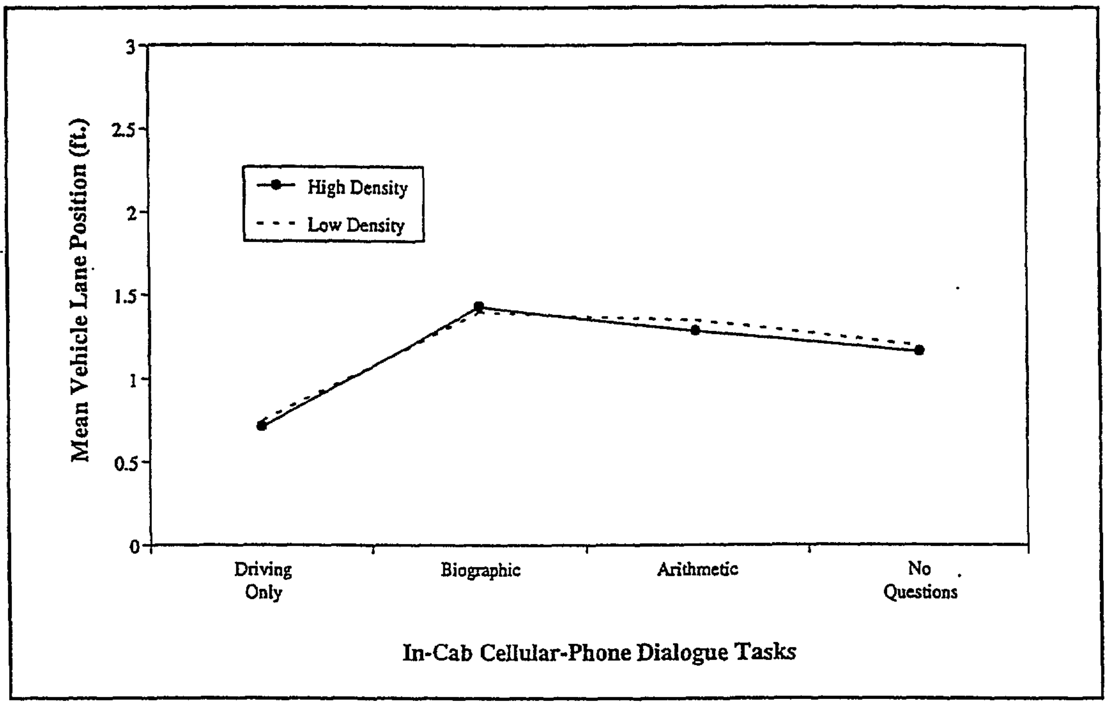


Figure 3. Mean Vehicle Lane Position as a Function of Traffic Density and Dialogue Task Event

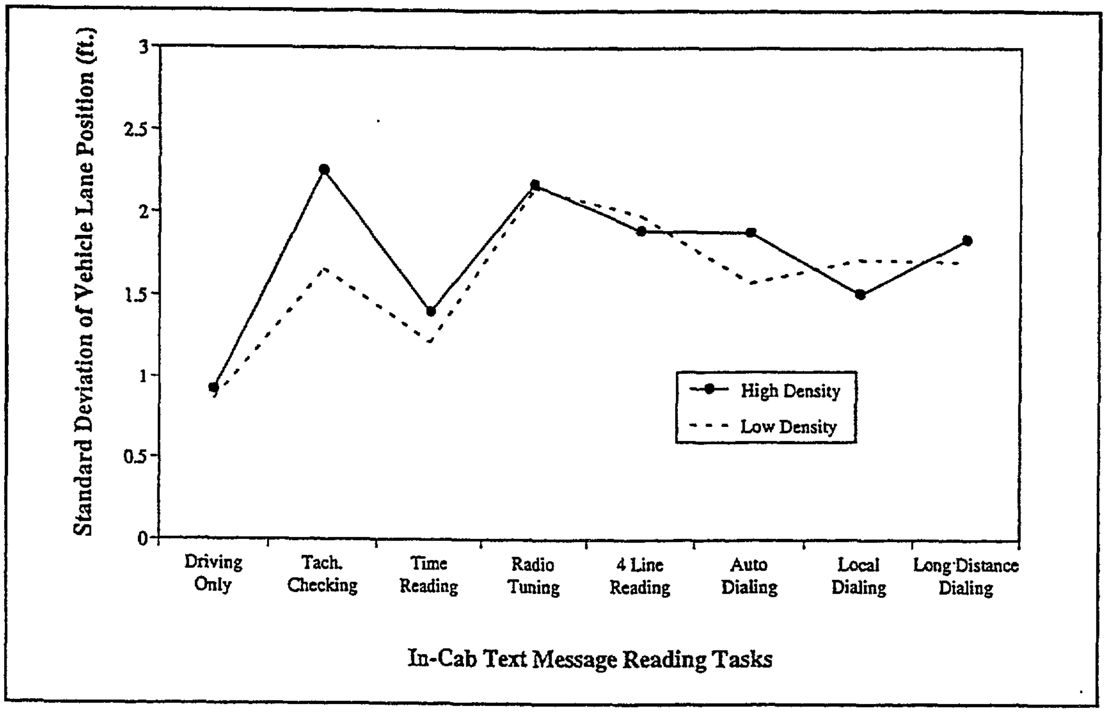


Figure 4. Standard Deviation Vehicle Lane Position as a Function of Traffic Density and In-Cab Text Message Reading Task Event

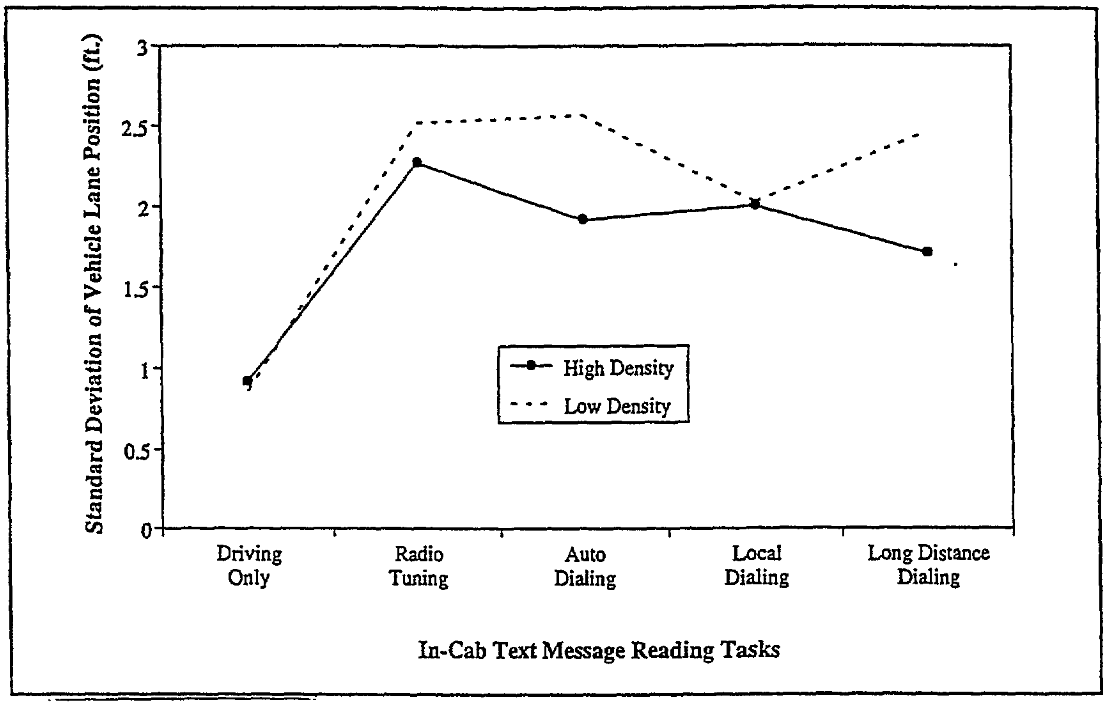


Figure 5. Standard Deviation Vehicle Lane Position as a Function of Traffic Density and Manual Task Event

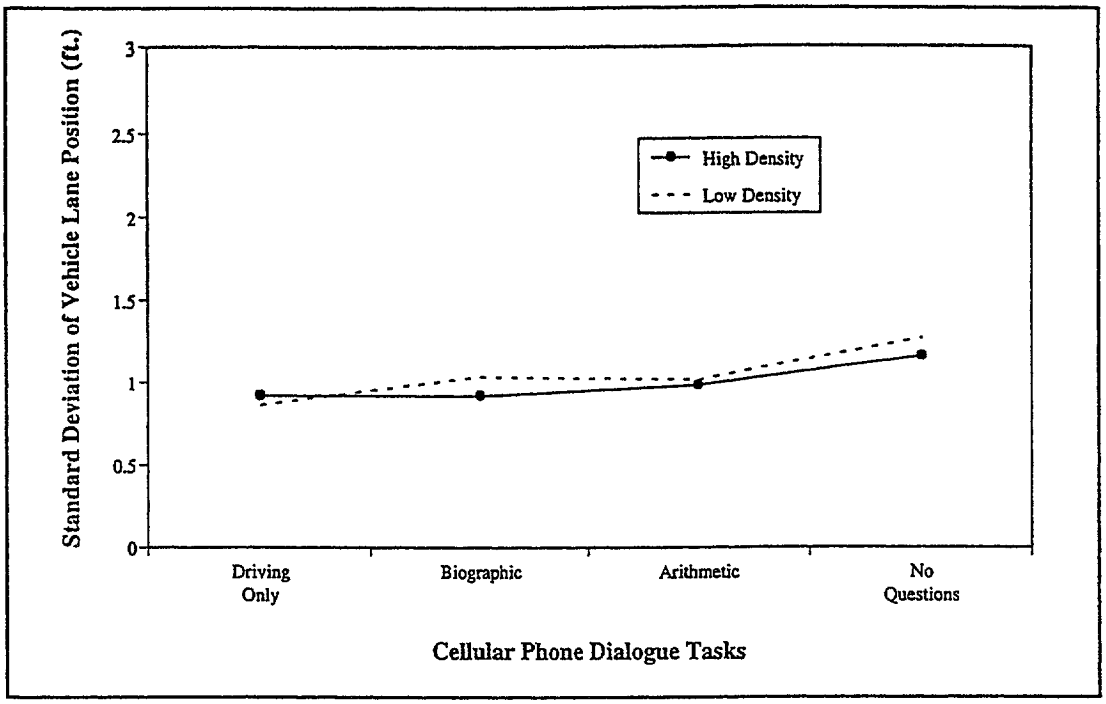


Figure 6. Standard Deviation Vehicle Lane Position as a Function of Traffic Density and Dialogue Task Event

3.1.3 Normalized Lane Exceedence Count

The normalized lane exceedence count refers to the frequency with which a driver exceeded his lane, accounting for the length of task. For example, a tachometer checking task was relatively short in duration, and therefore, would be more likely to have fewer instances of lane exceedence versus a cellular-phone dialing task, which was considerably lengthier. To account for the discrepancy in task duration, a normalized value of lane exceedence was calculated whereby the frequency of exceedences were calculated per one minute of driving. So that., for example, a tachometer checking task with a duration of 30 seconds, that had two lane exceedences, would have a normalized lane exceedence count of four. Similarly, a two minute dialing task that had 10 lane exceedences, would have a normalized lane exceedence count of five.

The data for normalized lane exceedence count are outlined in Figure 7 for the in-cab CRT text message reading tasks. A significant effect was found with in-cab CRT text message reading task, $F(7, 91) = 4.14$, $p < .00l$. Except for differences with the driving-only condition and several of the tasks (see Appendix 9), no differences were found between the various tasks (all p's > .05).

Normalized lane exceedence was also analyzed using traffic density and manual task events. These results are shown plotted in Figure 8. Manual task event proved to be significant, $F(4, 52) = 7.23$, $p < .00l$. A third analysis examined normalized lane exceedence as a function of traffic density and dialogue task event; however no results were significant.

3.1.4 Peak Lateral Lane Exceedence Distance

Peak lateral lane exceedence distance is defined as the maximum lateral distance observed in a sample interval. For example, during the radio tuning task, the driver may have recorded several lane exceedence instances in the interval lasting from task beginning to task end. The largest lateral distance associated with these exceedences was included as a dependent measure of driving performance. This measure is outlined in Figure 9 for the in-cab CRT text message reading tasks. As can be seen, a significant effect was found with the in-cab text message reading task, $F(7, 91) = 6.86$, $p < .00l$. Appendix 9 provides a table outlining the results of a multiple comparison analysis of the in-cab CRT text message reading tasks. Among other significant results, the driving-only condition had a significantly less peak lateral lane exceedence distance than all other tasks except for time reading, (all p's < .05). In addition, the radio tuning and 4-line reading tasks were found to have larger peak lateral lane exceedence distances than time reading, auto-dialing, and local-dialing tasks (all p's < .05).

Peak lateral exceedence is shown in Figure 10, plotted as a function of traffic density and manual task event. Traffic density proved to be significant, $F(l, 13) = 14.2$, $p <$ -002, as drivers had peak lateral exceedences of a lesser distance in the high traffic density condition

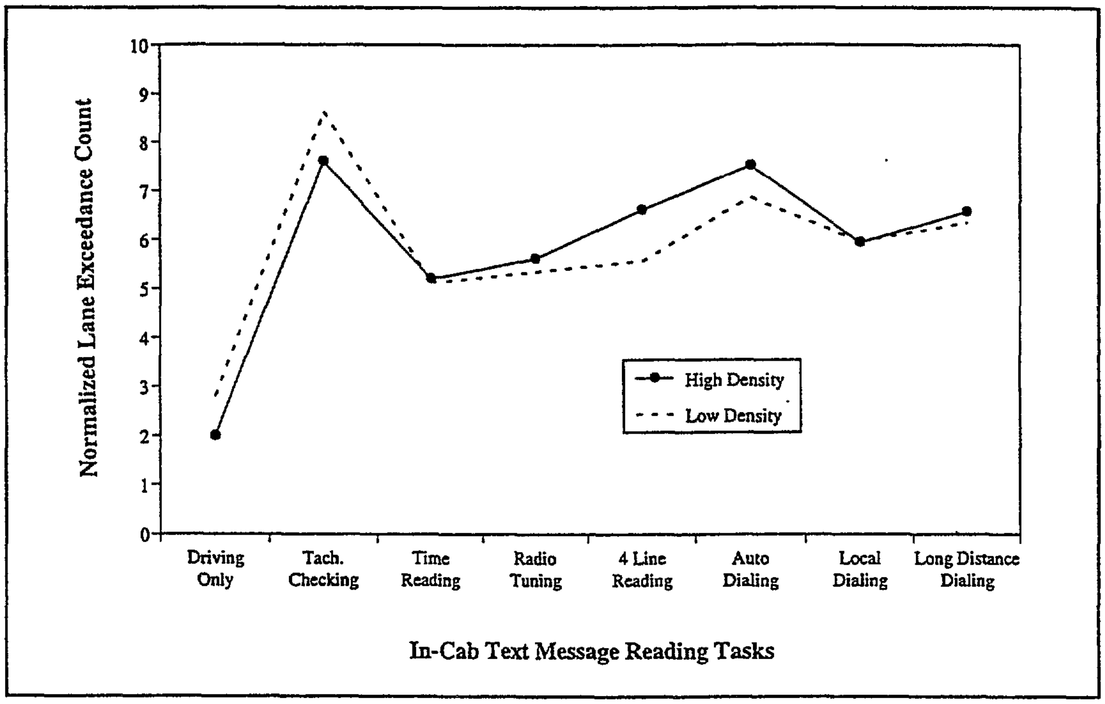


Figure 7. Normalized Lane Exceedence Count as a Function of Traffic Density and In-Cab CRT Text Message Reading Task Event

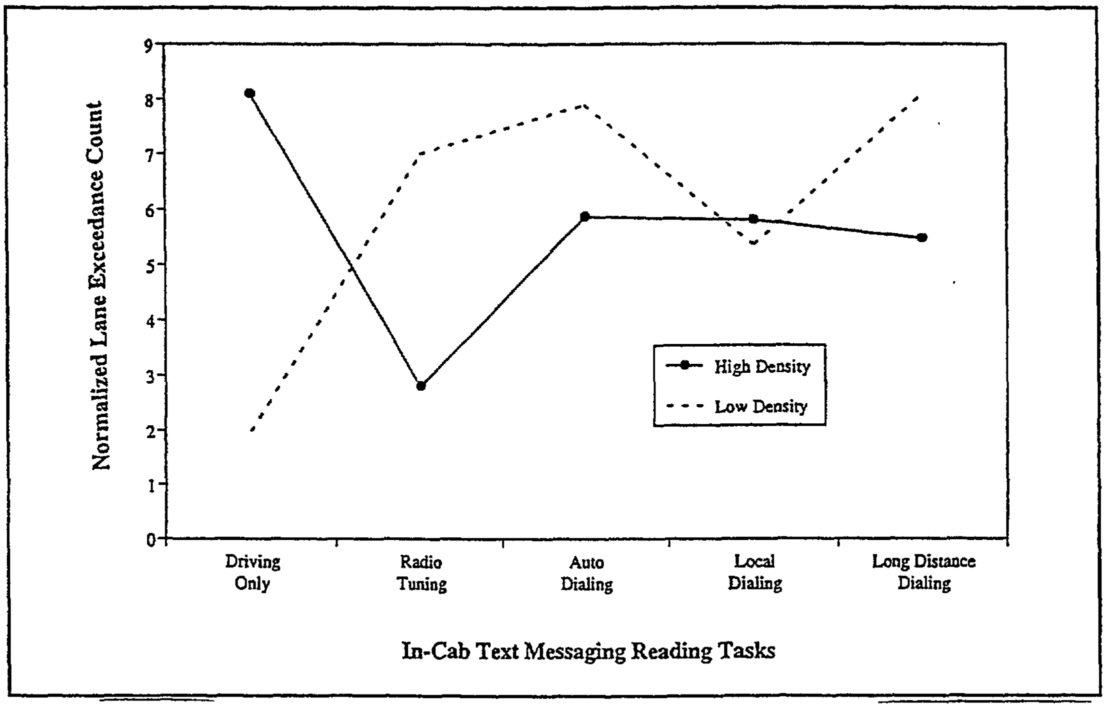


Figure 8. Normalized Lane Exceedence Count as a Function of Traffic Density and Manual Task Event

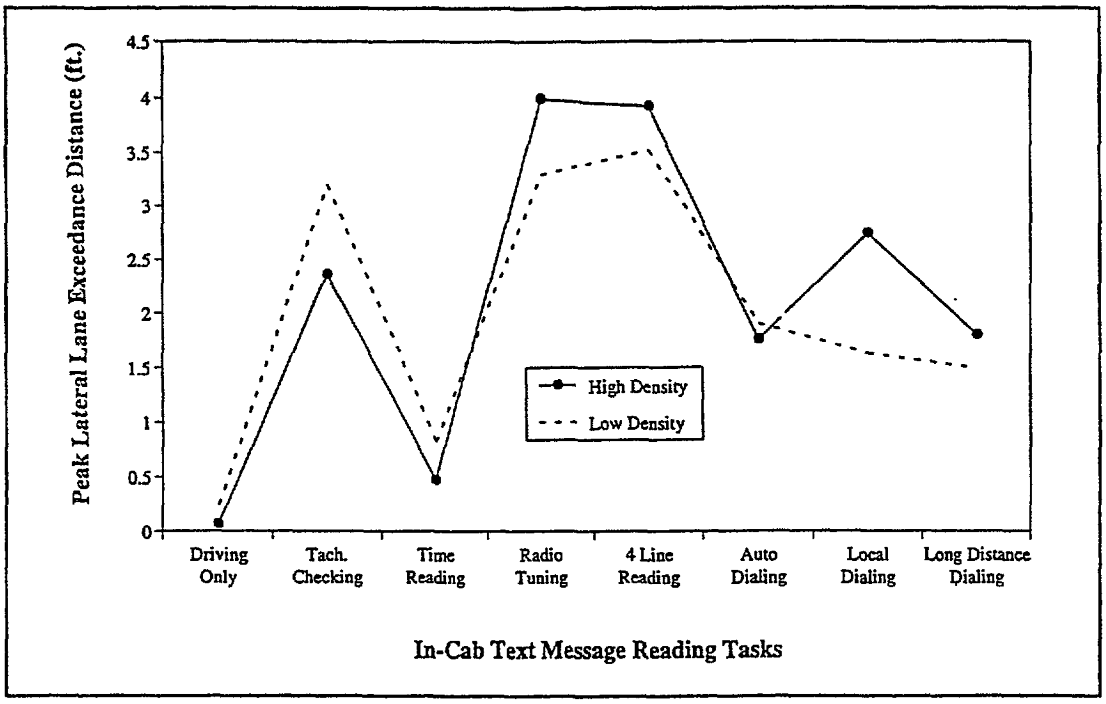


Figure 9. Peak Lateral Lane Exceedence Distance as a Function of Traffic Density and In-Cab CRT Text Message Reading Task Event

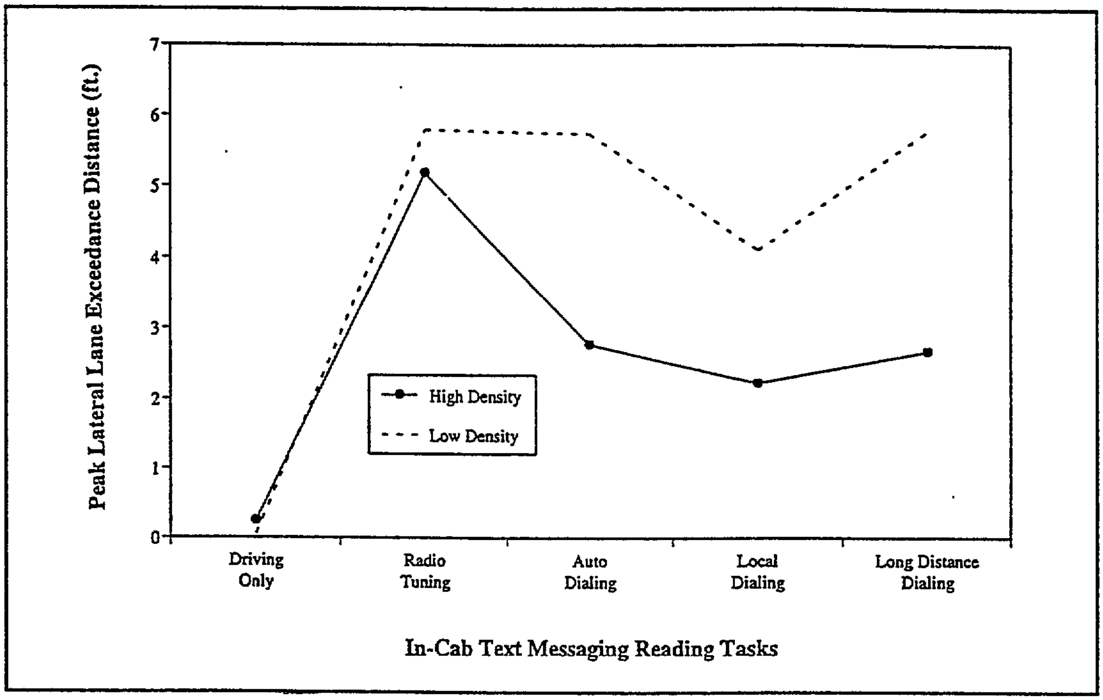


Figure 10. Peak Lateral Lane Exceedence Distance as a Function of Traffic Density and Manual Task Event

versus the low traffic density condition. Manual task event also proved to be significant; $F(4, 52) = 7.57$, $p < .00l$, with the driving-only condition significantly less than all other conditions (all p's < -05). All other manual tasks did not significantly differ (all p's > .05).

Peak lateral exceedence distance was also analyzed with traffic density and dialogue task. These data are outlined in Figure 11. Dialogue task event was found to be significant, $F(3, 39) = 10.0$, $p < .00l$. The driving-only condition was significantly different from both the biographic and arithmetic question sets (p's < .05). There was no difference between the question sets (all p's > .05).

3.1.5 Peak Longitudinal Lane Exceedence Distance

Peak longitudinal lane exceedence distance **is** defined as the maximum longitudinal distance observed in a sample interval. For example, for any given driver, the radio tuning task may have had several lane exceedence instances where the driver exited and re-entered his lane. The distance travelled outside the lane is referred to as the longitudinal exceedence distance. The largest of these, for a given task, is the peak longitudinal lane exceedence distance for that task. The data for peak longitudinal lane exceedence distance are shown in Figure 12. A significant effect of in-cab CRT text message reading task was found, $F(7, 91) = 7.54$, $p < .OOl$. The driving-only task had a smaller peak longitudinal lane exceedence distance than all other tasks except time reading (all p's < .05). Radio tuning and 4-line reading proved to have a larger peak longitudinal lane exceedence distance than tachometer checking, time reading, and long distance-dialing tasks (all p's < .05). The 4-line reading task also had a larger peak longitudinal lane exceedence distance than the auto-dialing task ($p < .05$).

Figure 13 shows peak longitudinal lane exceedence distance plotted as a function of traffic density and manual task event. Traffic density was significant, $F(l, 13) = 7.75$, $p < .02$, as drivers had less peak longitudinal lane exceedence distance values in the high traffic density conditions versus the low traffic density conditions. The driving-only condition was found to have significantly less peak longitudinal distances than all manual task events (all p's < .05). In addition, the radio tuning task proved to have higher distance values than auto-dialing, local-dialing, and long distance-dialing tasks (all p's < .05). No differences were found between the three dialing task types (all p's > .05).

A third analysis, plotted in Figure 14, with peak longitudinal distance was conducted using traffic density and dialogue task event. Dialogue task event proved to be significant, $F(3, 39) = 4.97$, $p < .005$. Follow-up comparisons found that the driving-only task significantly differed from all other tasks (all p's < .05), though the three dialogue tasks did not statistically differ (all p's > -OS).

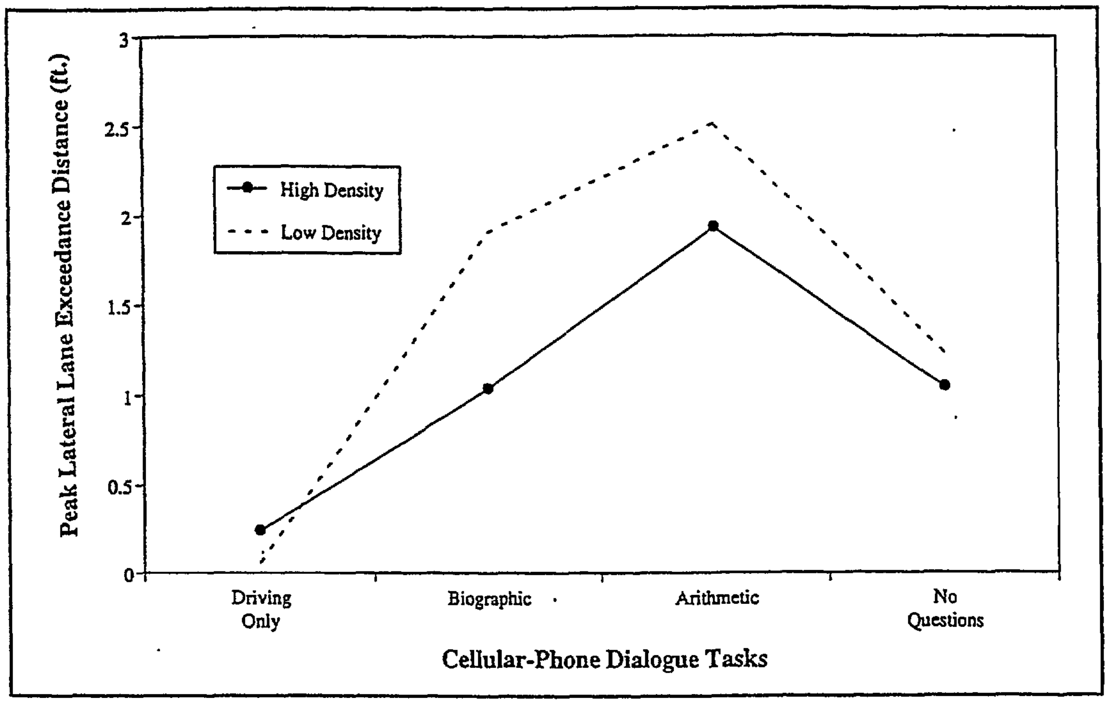


Figure 11. Peak Lateral Lane Exceedence Distance as a Function of Traffic Density and Dialogue Task Event

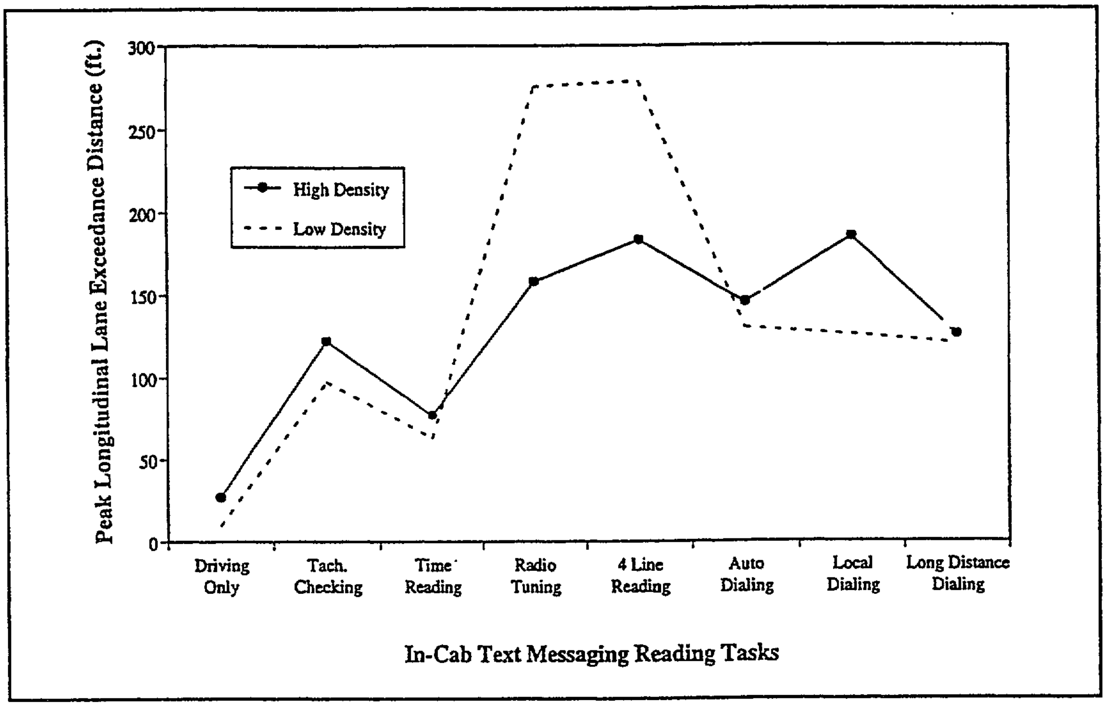


Figure 12. Peak Longitudinal Lane Exceedence Distance as a Function of Traffic Density and In-Cab CRT Text Message Task Event

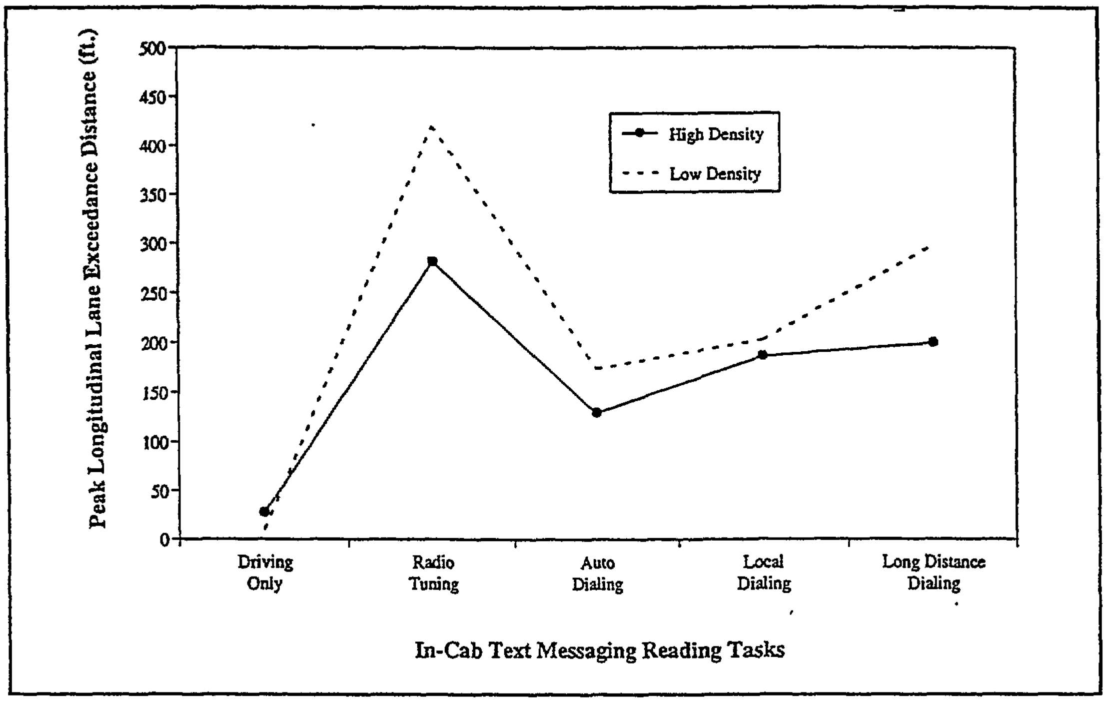


Figure 13. Peak Longitudinal Lane Exceedence Distance as a Function of Traffic Density and Manual Task Event

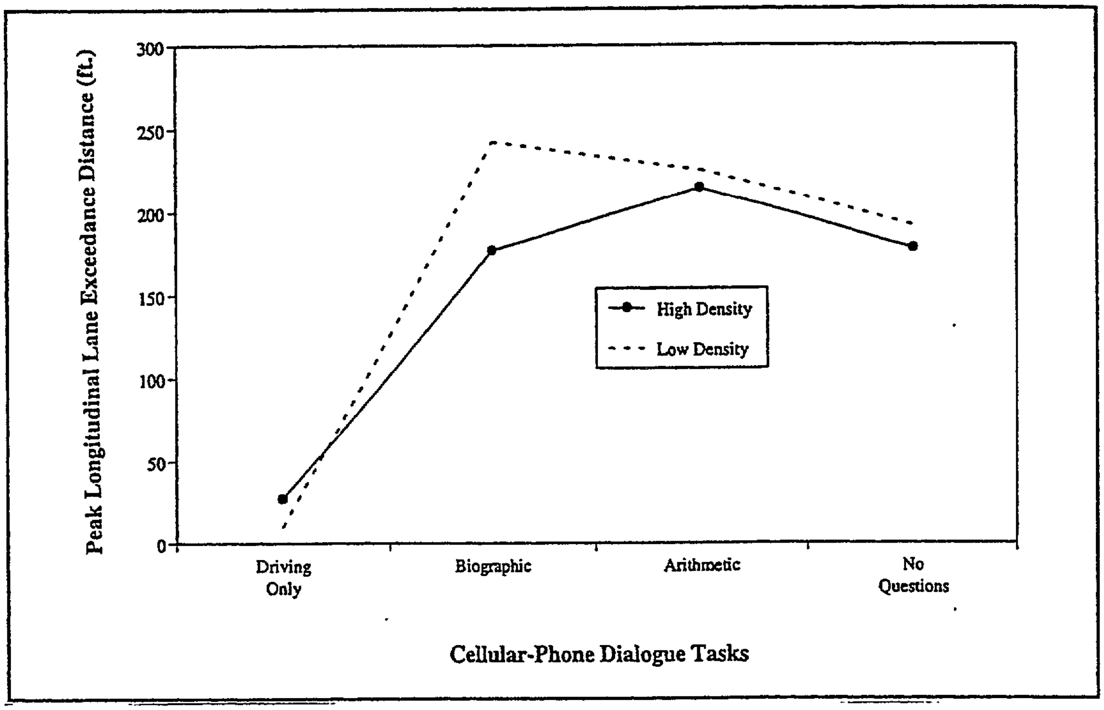


Figure 14. Peak Longitudinal Lane Exceedence Distance as a Function of Traffic Density and Dialogue Task Event

3.2 Vehicle Speed

For the eight in-cab text message reading tasks, including driving-only as a baseline, the mean vehicle speed values are outlined in Figure 15. Significant effects were found with traffic density, $F(l, 13) = 15.0$, $p < .002$, in-cab text message reading task, $F(7, 91) = 3.09$, $p < .04$, and a Traffic Density x In-Cab Text Message Reading Task interaction, $F(7, 91) = 2.42$, $p < .04$. As might be expected, drivers reduced their mean speed during heavy traffic scenarios. Additionally, as compared to the driving-only task, drivers significantly reduced their speed in time reading, 4-line reading, and local-dialing tasks (all p's < .05).

Analysis of vehicle speed was also conducted on traffic density and the manual task variables. These data are outlined in Figure 16. A significant Traffic Density x Manual Task Event was found, $F(4, 130) = 3.41$, $p < .02$.

For each level of in-cab text message reading task, the data for standard deviations of vehicle speed are outlined in Figure 17. In-cab text message reading task was significant, $F(7, 91) = 7.3$, $p < -001$. As compared to driving-only, drivers had significantly higher standard deviations of vehicle speed in the radio tuning, 4-line reading, and local-dialing tasks (all p's < .05). Also, speed deviations associated with the radio tuning task were found to be larger than that of tachometer checking, time reading, auto-dialing and long-dialing tasks (all p's < .05) Standard deviation vehicle speed was also analyzed using traffic density and manual task event, and traffic density and dialogue task, however no significant results were found.

3.3 Driver Steering Wheel Rate

The data for the mean driver steering wheel rate are shown in Figure 18. Significant effects were found with traffic density, $F(l, 13) = 25.0$, $p < .001$, in-cab text message reading task, $F(7, 91) = 2.33$, $p < .04$, and Traffic Density x In-Cab Text Message Reading Task, $F(7, 91) = 4.71$, $p < .005$.

Driver steering wheel rate was also analyzed using traffic density and manual task event. The data from this analysis are shown plotted in Figure 19. Significant effects were found with traffic density, $F(1, 13) = 42.2$, $p <.001$ and Traffic Density x Manual Task event, $F(4, 52) = 22.4$, $p < .00l$.

A third analysis was conducted with mean driver steering wheel rate using traffic density and dialogue task event. These results are outlined in Figure 20. Though significant differences were found with traffic density, $F(l, 13) = 30.3$, $p < .00l$, and Traffic Density x Dialogue Task event, $F(3, 39) = 25.8$, $p < .001$, it was likely the result of the data from the driving-only condition.

The data for the standard deviation steering wheel rate are shown in Figure 21. Significant effects were found with in-cab text message reading task, $F(7, 91) = 3.69$, $p < .008$, and Traffic Density x In-Cab Text Message Reading Task, $F(7, 91) = 3.74$, $p < .008$.

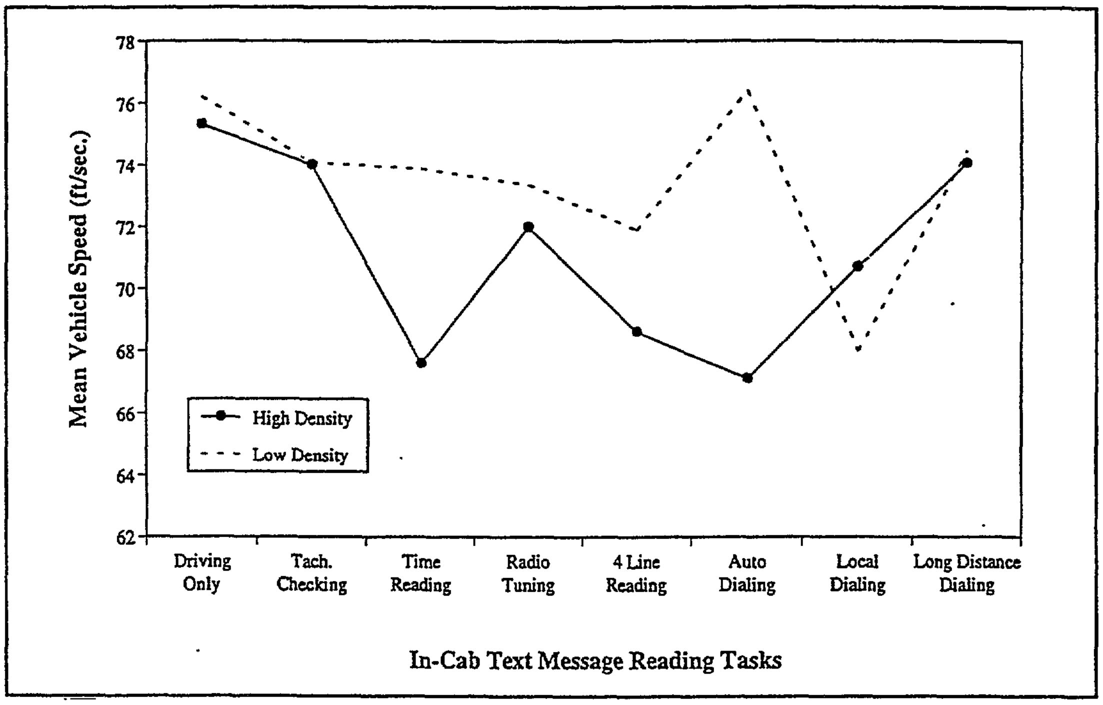


Figure 15. Mean Vehicle Speed as a Function of Traffic Density and In-Cab Text Message Reading Task

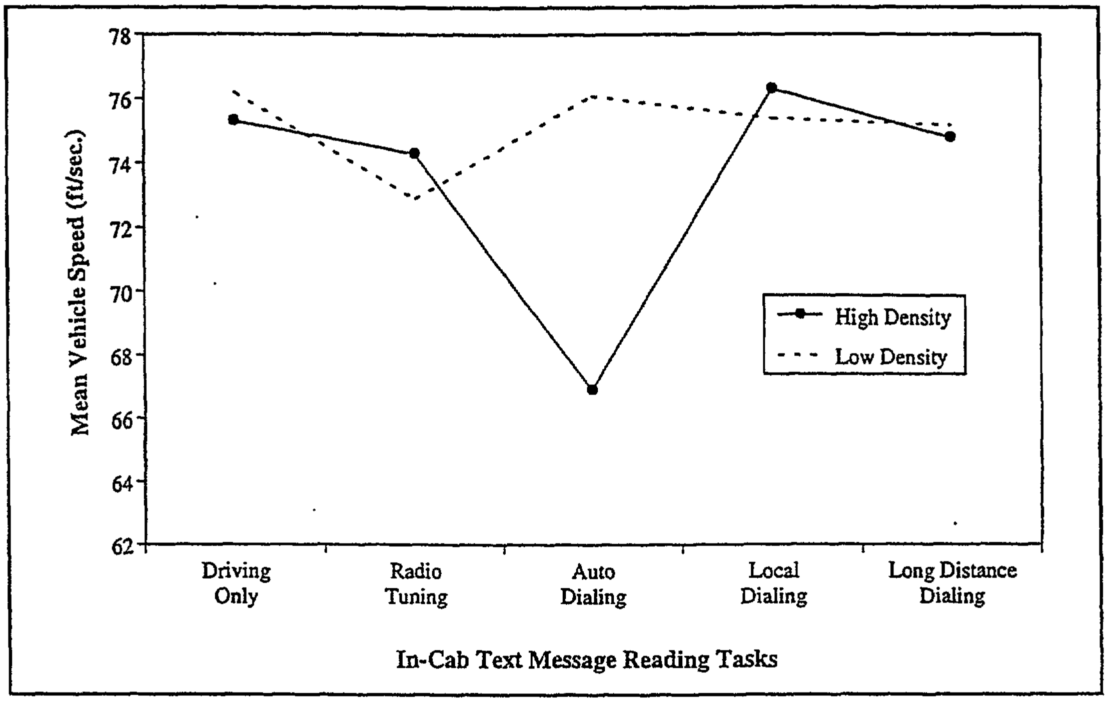


Figure 16. Mean Vehicle Speed as a Function of Traffic Density and Manual Task Event

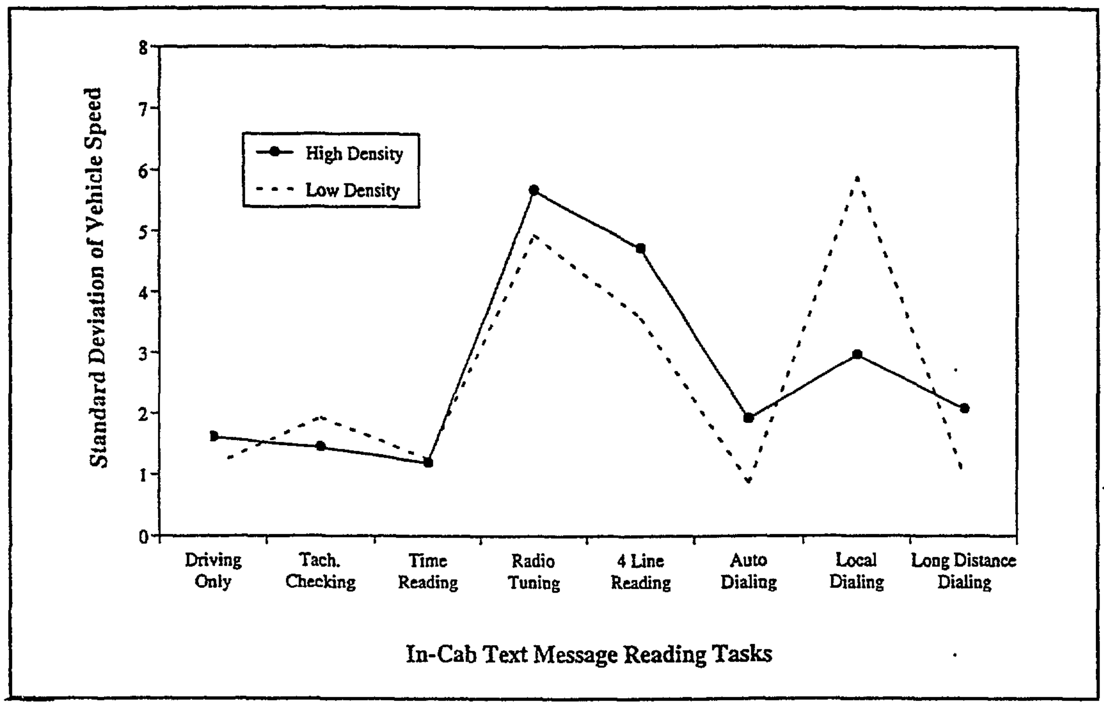


Figure 17. Standard Deviation Vehicle Speed as a Function of Traffic Density and In-Cab Text Message Reading Task Event

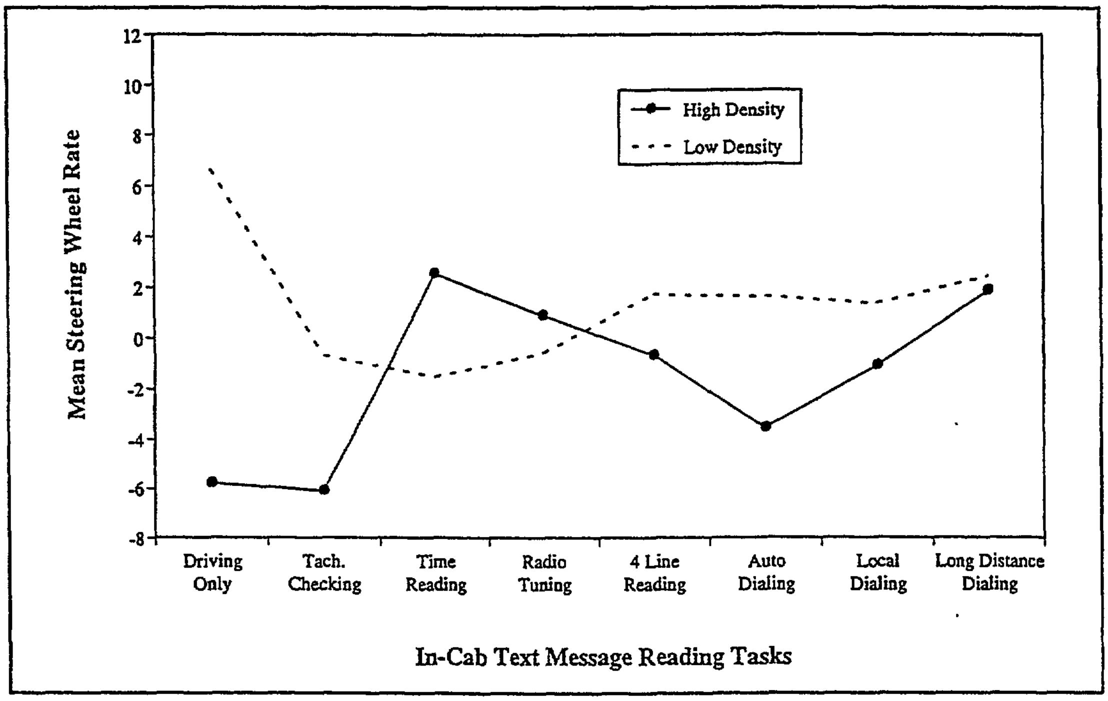


Figure 18. Mean Steering Wheel Rate as a Function of Traffic Density and In-Cab Text Message Reading Task Event

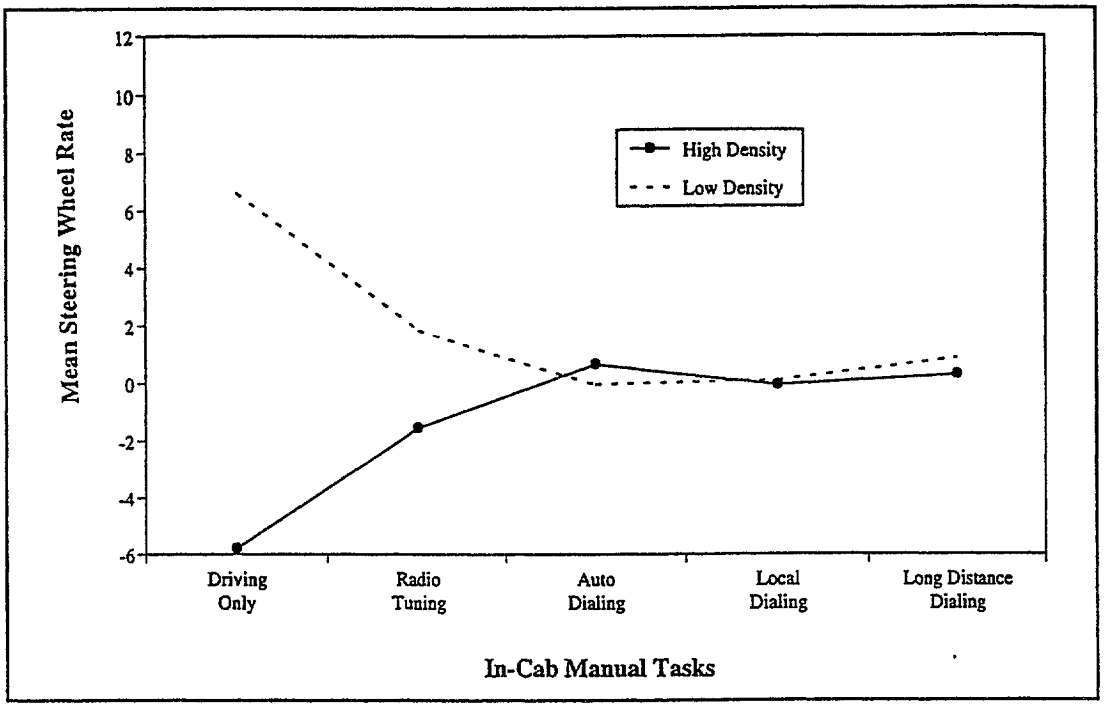


Figure 19. Mean Steering Wheel Rate as a Function of Traffic Density and Manual Task Event

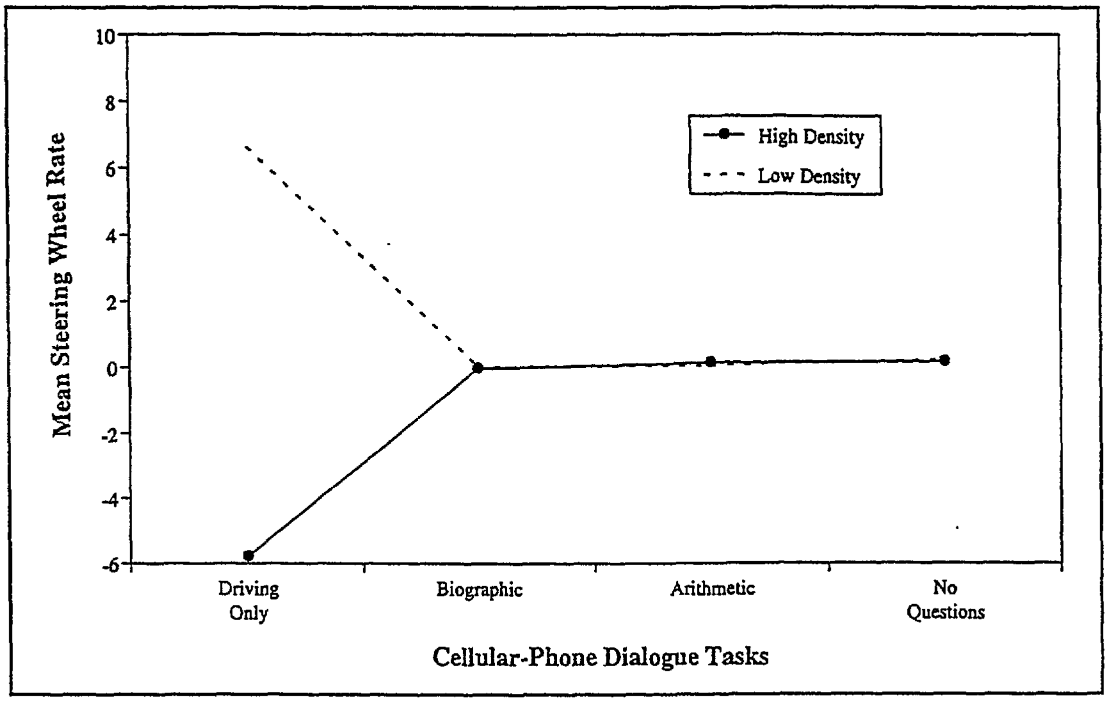


Figure 20. Mean Steering Wheel Rate as a Function of Traffic Density and Dialogue Task Event

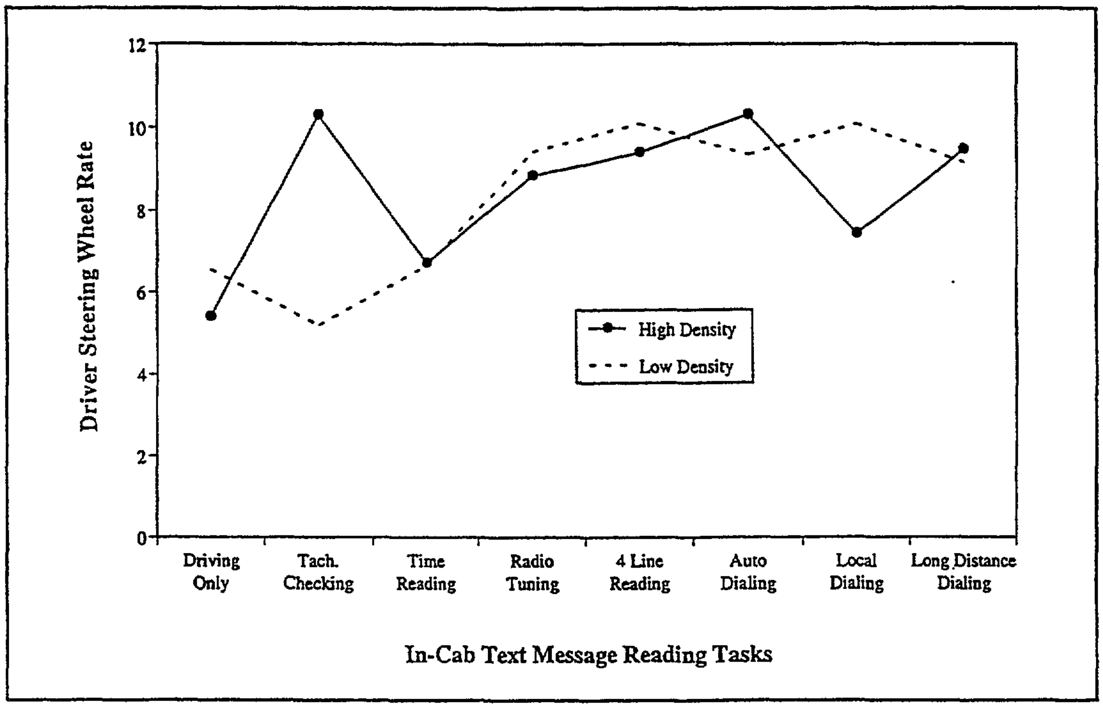


Figure 21. Standard Deviation Steering Wheel Rate as a Function of Traffic Density and In-Cab Text Message Reading Task Event

Standard deviations of steering wheel rate for the driving-only condition were significantly different from all other tasks, except time reading and tachometer checking (all p's < .0S). The time reading task was also found to differ from radio tuning, 4-line reading, auto-dialing, and long distance-dialing tasks (all p's < .05).

Standard deviation steering wheel rate was also analyzed with traffic density and manual task event. These data are outlined in Figure 22. Significantly less standard deviation steering wheel values were found in the high density traffic condition versus the low density traffic condition, $F(1, 13) = 6.66$, $p < .03$. Manual task event also proved to be significant, $F(4, 52) = 6.47$, $p < .001$. Standard deviations of steering wheel rate associated with the driving-only condition was significantly less than radio tuning, and auto-dialing tasks (p's < .05).

As outlined in Figure 23, standard deviation steering wheel rate was also analyzed with traffic density and dialogue task event. Dialogue task event proved to be significant, $F(3, 39) = 11.3$, $p < .001$. Comparisons of the levels of dialogue task found the driving-only condition to differ from both biographic and arithmetic question set conditions (p's < .05).

3.4 Object Detection Results

Two object detection performance measures were collected during the course of this experiment. They consisted of (1) percent object detection and (2) response latency. Percent object detection refers to the percent of pedestrians (i.e., objects) detected. Pedestrians would periodically cross the road in front of the driver or, alternatively, stand stationary at the side of the road. When the pedestrian crossed the road, the driver was required to press the horn button, located in the center of the steering wheel. The driver was not to press the horn button if the pedestrian was stationary at the side of the road. Therefore, correct object detection responses, scored as a "1", were pressing the horn when a pedestrian crossed the road and not pressing the button when a pedestrian was stationary at the side of the road. Incorrect object detection responses, scored as a "O", were failing to press the horn button when the pedestrian crossed the road, and pressing the horn button when the pedestrian was stationary at the side of the road.

Response latency refers to the reaction time to detect an object. Time began at the moment the object appeared in the driving scene, and ended when the driver pressed the horn button.

3.4.1 Percent Object Detection

An analysis was conducted that examined, in addition to traffic density, four distinct pedestrian events: (1) pedestrians that crossed the road, (2) pedestrians that were stationary at the side of the road, **(3)** cellular-phone dialing tasks that included a pedestrian crossing the road at the task onset, and (4) a 4-line message reading task that included a pedestrian crossing

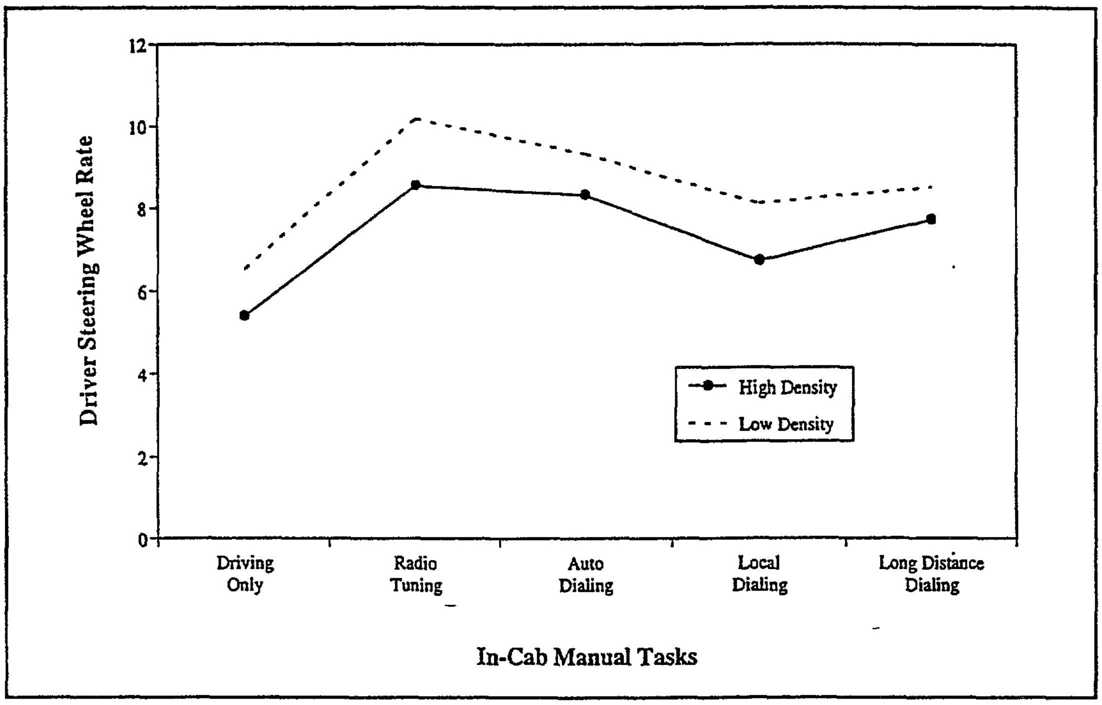


Figure 22. Standard Deviation Steering Wheel Rate as a Function of Traffic Density and Manual Task Event

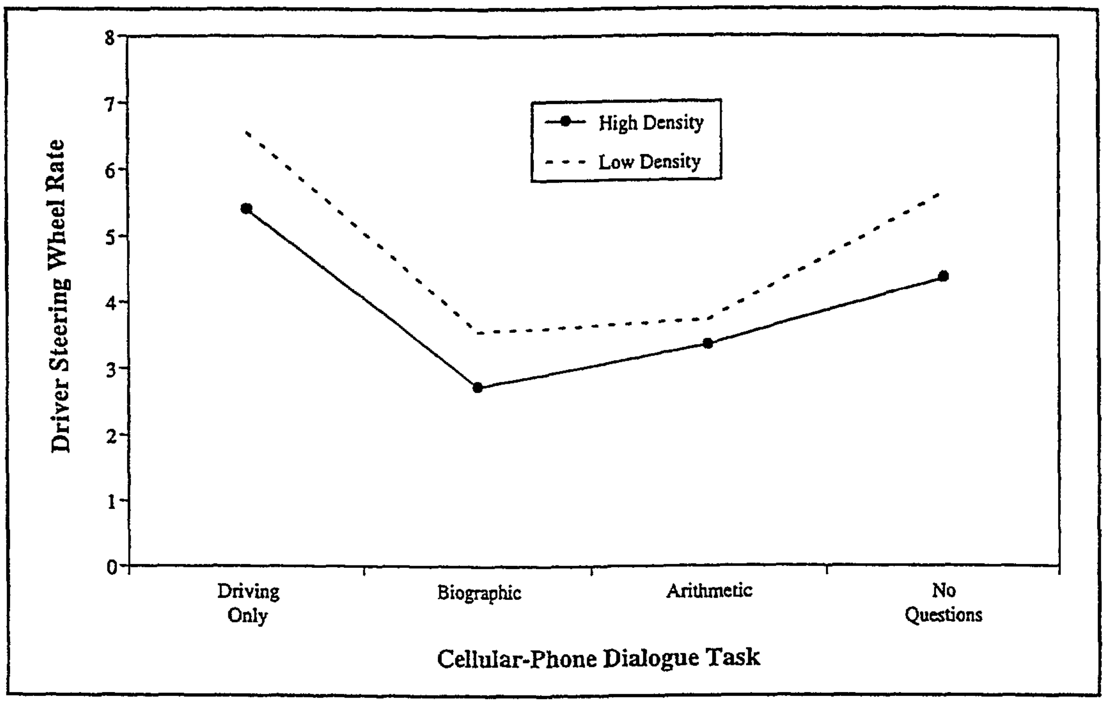


Figure 23. Standard Deviation Steering Wheel Rate as a Function of Traffic Density and Dialogue Task Event

the road at the task onset. As evident in Figure 24, the results of this analysis found no significant differences between either traffic density, or pedestrian events.

3.4.2 Object Detection Response Latency

Response latency refers to the time it took a driver to react to an object. Recall that these objects consisted of pedestrians that crossed the road in front of the driver, or remained stationary at the side of the road. A correct event response, referred to as a “hit”, was when the driver pressed the horn button when a pedestrian crossed. An incorrect event response, referred to as a “false alarm”, was when the driver pressed the horn button when a pedestrian was stationary. Drivers were instructed to press the horn button as soon as they saw a pedestrian crossing the road, but not to press the horn when they saw a stationary pedestrian. An analysis was conducted that examined response latency for both hits and false alarms, in heavy and light traffic conditions. As suggested by Figure 25, neither traffic density or event response proved to be significant (p’s $> .05$).

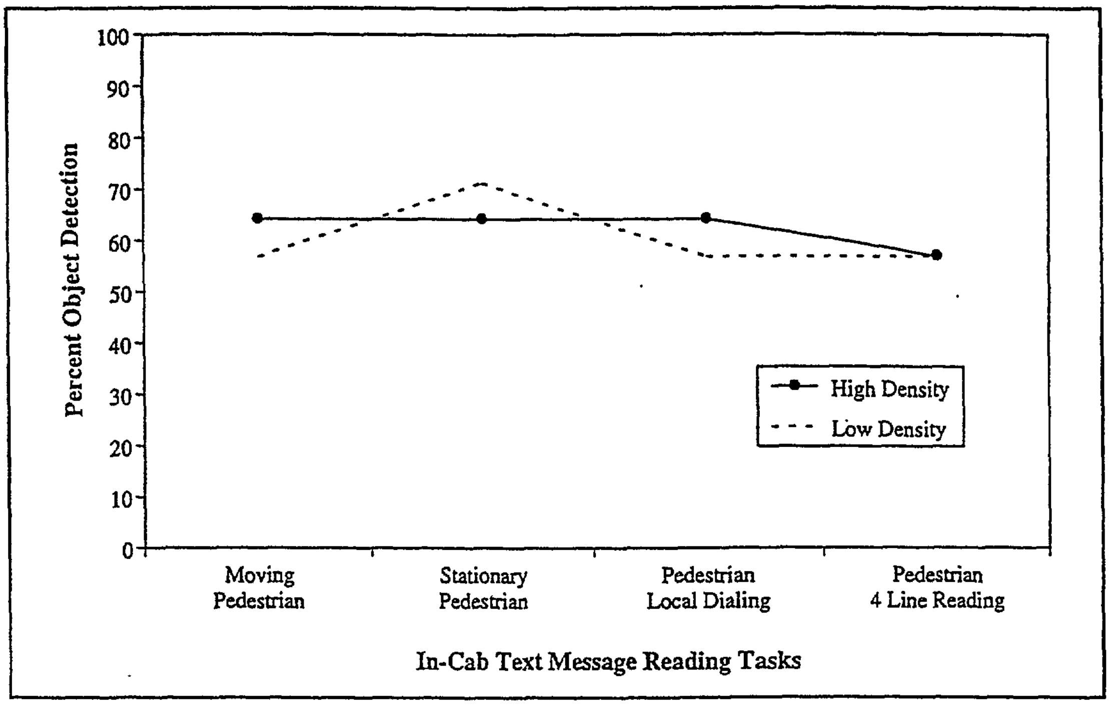


Figure 24. Percent Object Detection as a Function of Traffic Density and Pedestrian Events

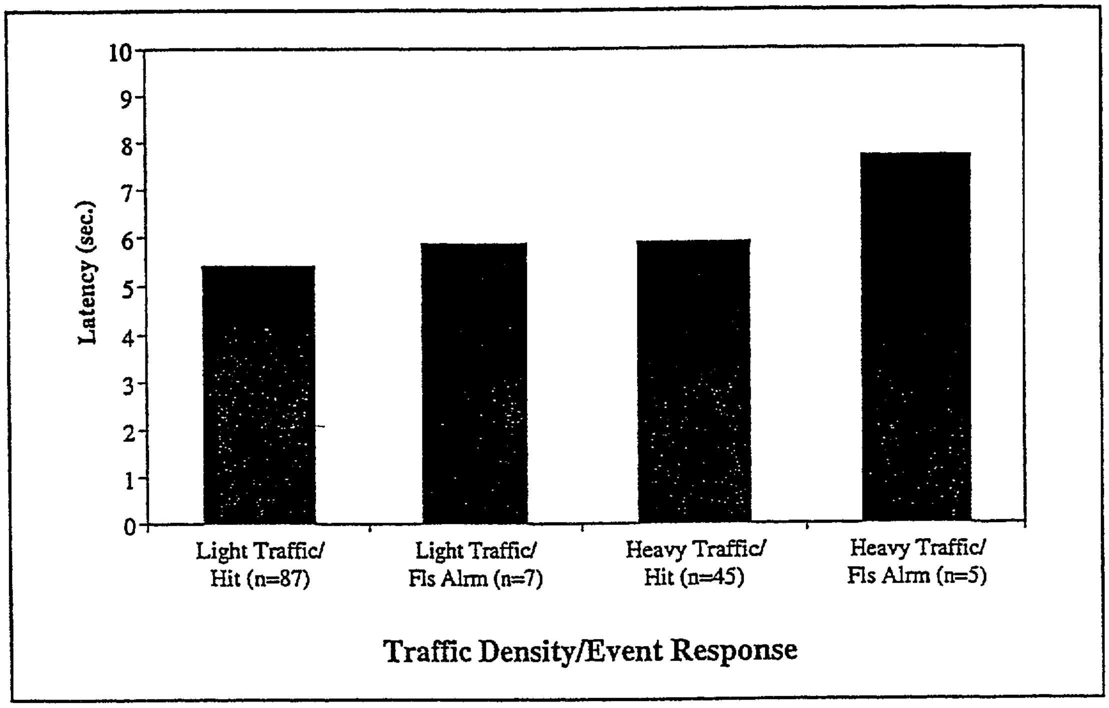


Figure 25. Response Latency as a Function of Traffic Density and Event Response

4.0 DISCUSSION

This study was intended to supplement the on-the-road evaluation of the text message system and cellular phone use reported on by Tijerina, Kiger, Rockwell, and Tornow (1995). The simulator study provided a number of measures that resemble those assessed in the on-the-road study. Comparisons between the simulator study results and those found in the on-the-road study are discussed below. The discussion is organized by consideration of selected effects of each type of in-cab transaction: CRT text message reading, manual tasks of cellular phone dialing (with radio tuning as a baseline), and question-and-answer dialogue (with open road driving as a baseline).

4.1 Effects During CRT Text Message Reading

The simulator study showed statistically significant mean lane position effects as a function of CRT text message type; the l-line time reading message was associated with the least mean vehicle position offset with respect to lane center. The on-the-road study, however, found no significant differences in this variable perhaps because on the road lane position offset is affected by other sources of variance not present in the simulator.

With respect to lane position standard deviation, Tijerina et al. (1995) reported that the greatest variability in lanekeeping in their over-the-road study was associated with the 2- and 4-line reading tasks, followed by the lo-digit phone number message. The simulator study found that lanekeeping variability was greater for the CRT tasks than for both the drive-only baseline and the time reading task. However, variability in lanekeeping tended to be undifferentiated across the CRT tasks in the simulator study. Furthermore, it appears that the lane position variability was greater overall in the simulator, perhaps because of the participants' perception of freedom from harm. Nonetheless, both studies support the notion that text message reading can negatively impact lanekeeping behavior, although the simulator results are unable to pinpoint differential text message effects on lanekeeping.

As regards vehicle speed, Tijerina et al. (1995) indicated that no practical differences in mean speed were found among the CRT reading tasks. The same can be said of drivers' speed as obtained in the simulator study. The on-the-road study revealed no practical differences for speed variability, and the simulator study results revealed small but statistically significant differences in speed variability among the CRT tasks. They found the 2- and 4-line reading and the local phone message to be associated with greater speed variability than normal driving. These two message types were also the most taxing in the field.

Steering measures collected in the simulator indicated that mean steering wheel rate was least for the driving only and the l-line "tachometer checking" message reading conditions, followed by the auto-dial message reading task. In the on-the-road study, steering position variance alone, was statistically significantly affected by message type, with 2-line (radio tuning) and 4-line (reading) messages being associated with the greatest steering variability.

Given the concurrent lack of significant differences in steering hold (not assessed in the simulator study), this was taken as indication that CRT message reading had no substantial workload effects on steering performance. It was hypothesized that with greater attentional demand away from the driving task, that steering variability would decrease because the driver momentarily engages in open-loop driving. The reason for the simulator study results may be similar to that found on the road, i.e., longer duration tasks provide a greater opportunity to capture variation in steering inputs, all else being equal.

For lane exceedences, Tijerina et al. (1995) found that most exceedances occurred when drivers had to read the 4-line text message, followed by the lo-digit dialing message. On the other hand, this simulator study found that while there were more lane exceedences while engaged in CRT text message reading than driving only, the 4-line reading message and the lo-digit dialing message are not associated with the most lane exceedences, using a normalized count. Thus, there appears to again be less sensitivity to text message type in the simulator than on the road.

With respect to traffic density, Tijerina et al. (1995) reported no practical differences between levels of traffic density. Traffic density also played no role in driver-vehicle performance for this simulator study.

4.2 Effects During Manual Tasks

There is little overlap between the two heavy vehicle driver workload studies with respect to the performance of the manual tasks. In the simulator study, mean lane position was closest to lane center for the auto-dial task and furthest for the radio tuning task. In the field study, there were no reliable effects of manual task on mean lane position, lane variability, or lane exceedences. In the simulator study, lane standard deviations during manual task execution were less in high traffic density than in low. No such effects were found in the on-the-road study. Finally, there were no significant differences in lane exceedences across the manual tasks in the on-the-road study. This is taken as an indication that the heavy vehicle driver on the road allocates attention to maintain adequate lanekeeping, but the simulator environment apparently prompts somewhat different behaviors.

There were statistically significant differences in mean speed variance in the on-the-road study as a function of manual task. The lowest speed variation was associated with the auto-dialing task. No such results were found in the simulator study, perhaps because factors that might increase speed variability on the road (e.g., wind gusts, road grade variations) were absent from the part-task simulation.

4.3 Effects During Cognitive (Dialogue Tasks)

Tijerina et al. (1995) reported that driver-vehicle performance in terms of lanekeeping and speed maintenance did not degrade during the performance of the cognitive tasks. This is not wholly the case for simulator study with respect to lanekeeping. For mean lane position, drivers in the simulator tended to stay closer to the center lane marking during baseline driving than when performing each of the cognitive tasks. In terms of lane exceedences (normalized counts), the simulator study found both the biographic and the arithmetic dialogue to be associated with greater numbers of lane exceedences than driving only. Such was not the case in the on-the-road study; no significant differences were found between the dialogues and the baseline of open road driving for lanekeeping or speed maintenance. This again suggests that heavy vehicle drivers in the simulator adopt a more lax attitude toward lanekeeping because there is no safety risk associated with degraded lanekeeping.

4.4 Concluding Remarks

The use of a part-task driving simulator in lieu of on-the-road field testing offers several potential advantages. The necessary resources are likely to be less. There is more control over variables like road curvature, presence of intersections, and the ability to program events (e.g., lead vehicle brakes, pedestrian steps into travel lane), and so forth. The use of a part-task simulator should also provide for a very safe workload assessment because there will be no consequences associated with errors in judgement or unacceptable workload management .

On the other hand, driving simulators have limitations that demand caution in their application. If the simulator is sophisticated, a simulator study may be as costly as an on-the-road study. Unless the simulator is sophisticated, it is not possible to accurately simulate certain driving condition variables such as ambient lighting and the behavior of other vehicles. Simulators vary in their visual scene generation capability and the effects of motion in simulators is only incompletely understood. The driving simulator can, at least in principle, generate an enormous amount of data so that the data reduction and analysis tasks are not appreciably less than that from a well-run field study. Finally, precisely because there are no consequences to neglecting the driving task, it is an open question about whether the results of a simulator-based workload assessment are comparable to what would have been found in the real world.

Smiley (1995) has recently pointed out that road tests can often be criticized as also being “simulations” of real driving due to experimental procedures implemented to minimize safety risks and experimental variability. However, Smiley also acknowledges that prior to full deployment of a technology, on-the-road naturalistic driving studies are necessary. Thus, it appears that the driving simulator can play a role in preliminary device workload assessments. The final device evaluation should, however, be conducted on the road in as naturalistic a driving situation as possible. With the advent of portable data acquisition systems that can be mounted onto vehicles so as to capture data with minimal intrusion, it should be possible to capture truly “normal” driving and in-cab device use, from which the final workload assessment may be made.

REFERENCES

Smiley, A. (1995). ***Overview and methodologies of the ITS safety evaluation process.*** Paper presented at the ITS AMERICA/NHTSA Workshop on ITS Safety Evaluations, Reston, VA, May l-2, 1995.

Tijerina, L, Kiger, S. M., Rockwell, T. H., & Tornow, C. E. (1995, September). ***NHTSA heavy vehicle driver workload assessment final report -- Workload assessment of in-cab text message system and cellular phone*** use ***by heavy vehicle drivers on the road*** (Contract No. DTNH22-9 l-C-07003). Columbus, OH: Battelle.

APPENDIX 1

Figure A.1 Exterior of simulator truck cab.

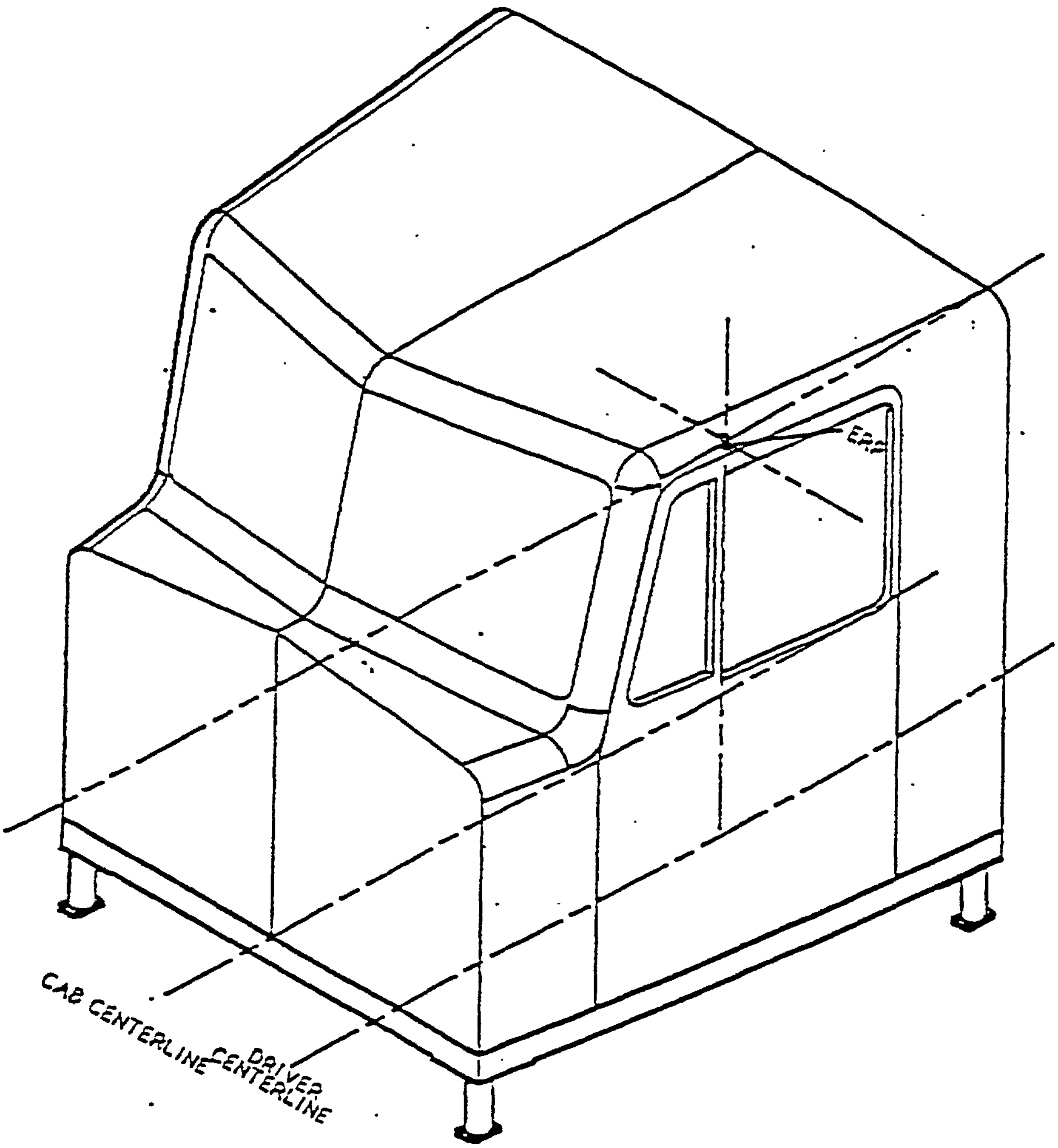


Figure A.2 Rear view of simulator truck cab.

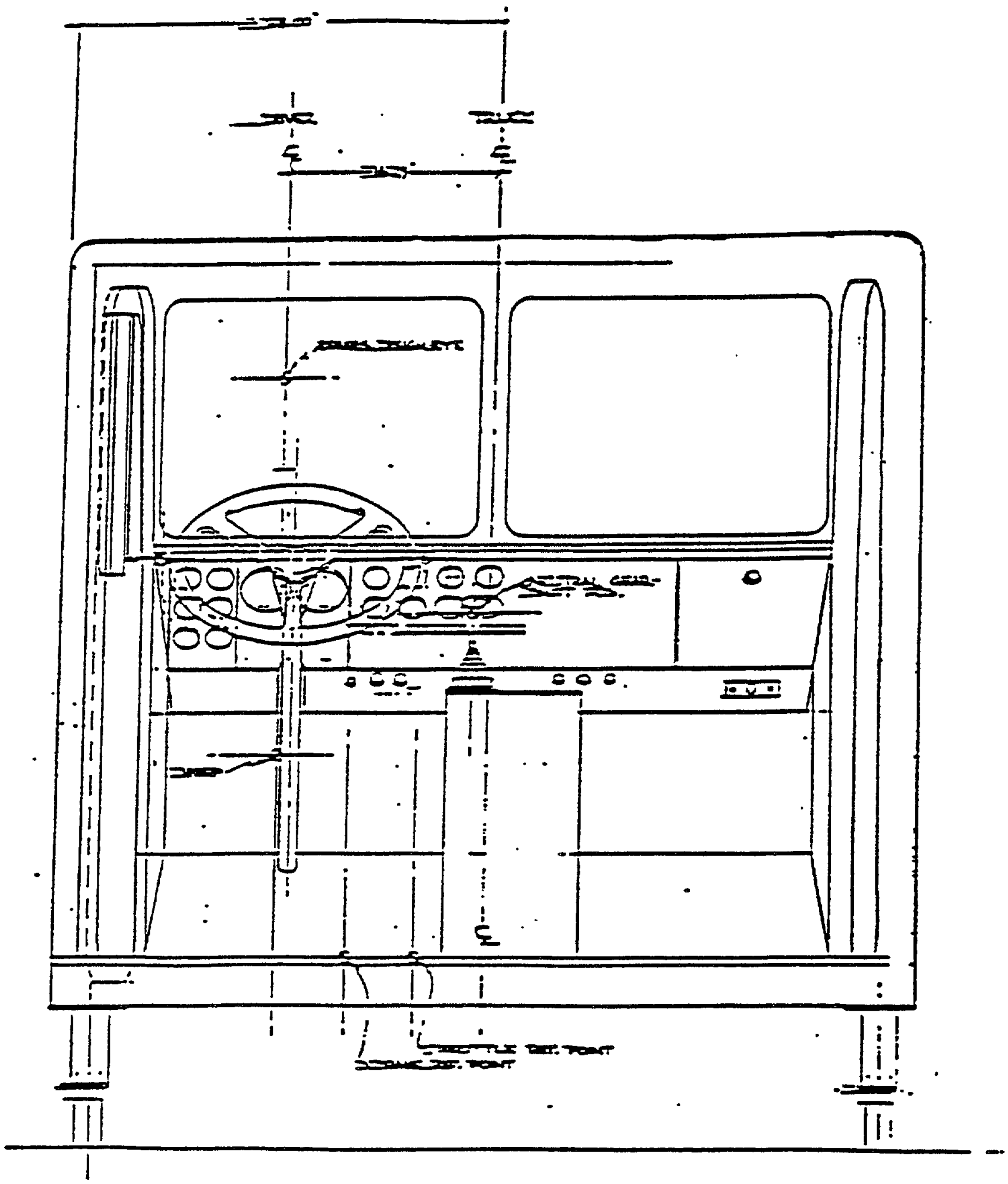


Figure A.3 Plan view of simulator truck cab.

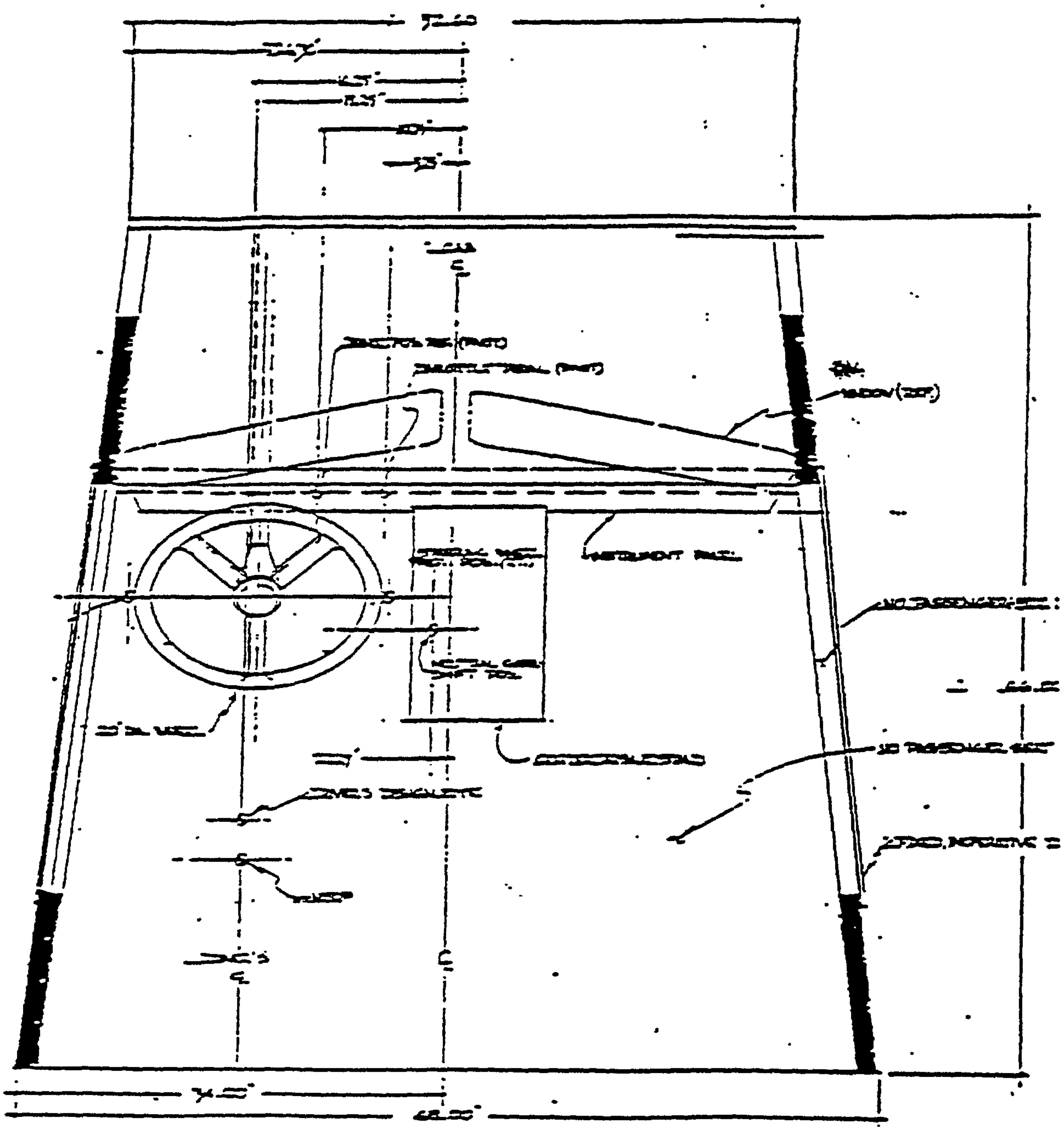
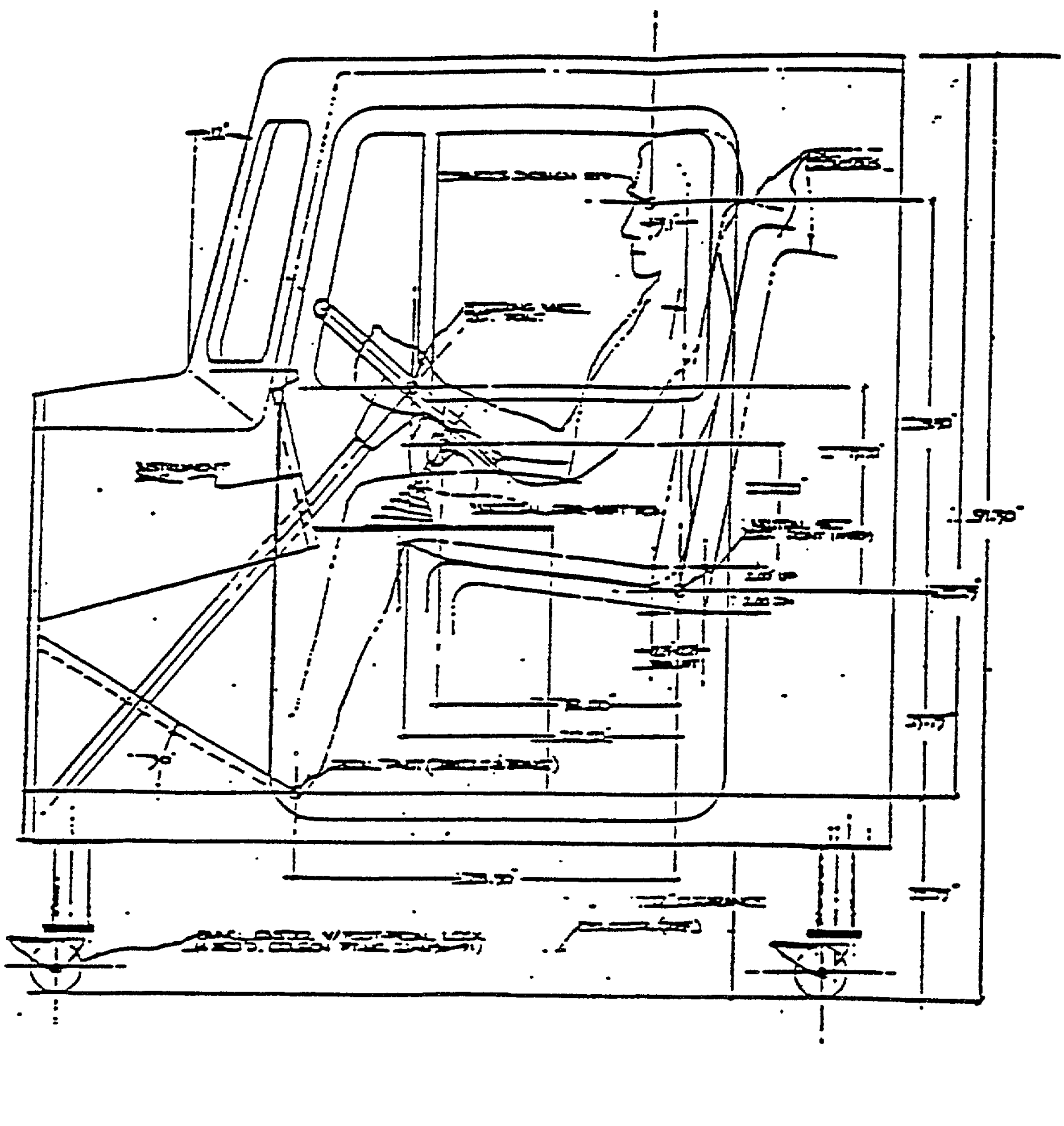


Figure A.4 Inboard profile of simulator truck cab.



APPENDIX 2

BIOGRAPHIC INFORMATION (LOW WORKLOAD) MESSAGE SETS

Recording will ask:

Set 1:

"Hello. Please state your first and last name."
<7 s pause>
"What is your date of birth?"
<7 s pause>
"What is your current age?"
<7 s pause>
"Where is your place of birth?"
<7 s pause>
"What is your current address?"
<7 s pause>
"In what states, other than Washington, have you lived?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

Set 2:

"Hello. Please state your first and last name."
<7 s pause>
"Where did you attend elementary school?"
<7 s pause>
"Where did you last attend or graduate from high school?"
<7 s pause>
"Do you have any formal schooling beyond high school?"
<7 s pause>
"Where did you learn to drive?"
<7 s pause>
"Did you serve in the military?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

Set 3:

"Hello. Please state your first and last name."
<7 s pause>
"How many years have you been driving a truck?"
<7 s pause>
"State your years experience with 48ft or longer trailers"
<7 s pause>
"Have you ever driven double or triple trailers?"
<7 s pause>
"About how many miles did you drive a truck last year?"
<7 s pause>
"Who is your current employer?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

Set 4:

"Hello. Please state your first and last name."
<7 s pause>
"What is your height in feet and inches?"
<7 s pause>
"Do you write with your right hand or your left hand?"
<7 s pause>
"Do you wear any corrective lenses and, if so, what kind?"
<7 s pause>
"Do you ever wear sunglasses when you drive a truck?"
<7 s pause>
"Before today, about how many times have you used a cellular phone?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

ARITHMETIC (MODERATE WORKLOAD) MESSAGE SETS

Recording will ask:

Set 1:

"Hello. Please state your first and last name."
<7 s pause>
"Please answer the following questions."
<5 s pause>
"How long have you been driving today?"
<7 s pause>
"How much longer can you drive today before you reach the limit?"
<7 s pause>
"How long will it take you to make a 200 mile run if you average 40 miles per hour?"
<7 s pause>
"How many gallons of fuel are needed to drive 350 miles?"
<7 s pause>
"How many miles will you drive in two-and-a-half-hours if you average 50 miles per hour?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

Set 2:

"Hello. Please state your first and last name."
<7 s pause>
"Please answer the following questions."
<5 s pause>
"How long have you been driving today?"
<7 s pause>
"How much longer can you drive today before you reach the limit?"
<7 s pause>
"How long will it take you to make a 200 mile run if you average 50 miles per hour?"
<7 s pause>
"How many gallons of fuel are needed to drive 200 miles?"
<7 s pause>
"How many miles will you drive in three-and-a-half-hours if you average 40 miles per hour?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

Set 3:

"Hello. Please state your first and last name."
<7 s pause>
"Please answer the following questions."
<5 s pause>
"How long have you been driving today?"
<7 s pause>
"How much longer can you drive today before you reach the limit?"
<7 s pause>
"How long will it take you to make a 120 mile run if you average 40 miles per hour?"
<7 s pause>
"How many gallons of fuel are needed to drive 250 miles?"
<7 s pause>
"How many miles will you drive in two-and-a-half-hours if you average 60 miles per hour?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

ARITHMETIC (MODERATE WORKLOAD) MESSAGE SETS (CONTINUED)

Set 4:

"Hello. State your full name."
<7 s pause>
"Please answer the following questions."
<5 s pause>
"How long have you been driving today?"
<7 s pause>
"How much longer can you drive today before you reach the limit?"
<7 s pause>
"How long will it take you to make a 150 mile run if you average 50 miles per hour?"
<7 s pause>
"How many gallons of fuel are needed to drive 300 miles?"
<7 s pause>
"How many miles will you drive in three-and-a-half-hours if you average 50 miles per hour?"
<7 s pause>
"Thank you for the information. You may now hang up. Good-bye."

APPENDIX 3

TEXT MESSAGES

1-LINE:

"What is the current time?"

"What is the Tachometer value?"

"Auto-Dial with RCL 01."

"Auto-Dial with RCL 02."

"Auto-Dial with RCL 03."

"Auto-Dial with RCL 04."

"Dial 528-3280 for questions."

"Dial 528-3281 for questions."

"Dial 528-3282 for questions."

"Dial 528-3284 for questions."

"Dial 528-3286 for questions."

"Dial 528-3287 for questions."

"Dial 206-528-3282 for questions."

"Dial 206-528-3285 for questions."

"Dial 206-528-3286 for questions."

2-LINE:

"Possible delay at I-5 and Denny Way.
For details, tune radio to 99.9 FM."

"Possible delay on I-405 through Bellevue.
For details, tune radio to 101.5 FM."

"Possible delay on I-5 at Northgate.
For details, tune radio to 88.9 FM."

"Possible delay on I-405 at the 520 exit.
For details, tune radio to 106.9 FM."

"Possible delay on the 520 bridge eastbound.
For details, tune radio to 101.5 FM."

"Possible delay on I-90 through Mercer Island.
For details, tune radio to 88.3 FM."

"Possible delay on SR-99 through Lynwood.
For details, tune radio to 97.7 FM."

"Possible delay on SR-169 through Black Diamond.
For details, tune radio to 103.5 FM."

"Possible delay on I-405 at the 522 exit.
For details, tune radio to 98.5 FM."

"Possible delay on I-5 through downtown.
For details, tune radio to 95.5 FM."

"Possible delay on Highway 2 near Sultan.
For details, tune radio to 97.3 FM."

"Possible delay on SR-203 through Duvall.
For details, tune radio to 94.7 FM."

"Possible delay on SR-202 north of Redmond.
For details, tune radio to 92.7 FM."

"Possible delay on SR-527 through Mill Creek.
For details, tune radio to 102.3 FM."

"Possible delay on SR-104 at the SR-99 exit.
For details, tune radio to 105.1 FM."

4-LINE:

"Please read this message out loud...
Road construction on I-5 north and
south in downtown Seattle restricts
traffic to left two lanes."

"Please read this message out loud...
Expect delays on I-90 eastbound
at I-405 exit for next hour due to
traffic accident in right lane."

APPENDIX 4

Demographic Questionnaire

Identification Number______.

1. Name: ______________________________

2. Gender: ___female ___male

3. Age: (check one of the following)

___Under 31 ___51-64
___31-40 ___65-74
___41-50 ___75 and over

4. How many years have you been driving a truck?__________________.

5. How many years have you had a commercial drivers license (CDL)?________.

6. What type of CDL endorsement do you have? (check all that apply)

___air brakes ___double/Triple Trailer

___tank ___hazardous Materials

___passenger

7. What type of truck do you usually drive?

___single unit ___tractor/semi-trailer

___tractor/semi- and full-trailer

___other (please specify)______________________________.

8. How many commercial miles did you travel in the last year?__________.

9. What is your typical operating weight (GVW)?__________________.

10. What is your maximum operating weight (GVW)?_________________.

11. How many hours per day do you personally drive?________________.

12. How many hours per day is your vehicle in operation?_____________.

13. How many miles per year does your vehicle average? ______________.

14. How would you describe your typical cargo (e.g., household goods, perishable food, fuel, automobiles, etc.)? ____
____.

15. Do you typically operate (check one):

____cross country (over 250 miles)

____regional line hauls (90 to 250 miles)

____local line hauls (less than 90 miles)?

16. If you operate cross country, in how many states do you operate? _________.

17. Are you:

____an ICC carrier ____ICC exempt

____leased ____fleet

____gov't fleet ____other (please specify)

18. Are you currently:

____an independent truck driver

____employed by a firm

APPENDIX 5

NHTSA RESEARCH PARTICIPATION CONSENT FORM
(G2048-1401)

You have been recruited to participate in a study that will examine the effects that in-vehicle communication systems have on driver performance. These systems allow the driver to receive and send messages outside the cab. Your participation will include "driving" a truck on a simulator. There are 2 risks associated with this experiment: (1) You may experience motion sickness while driving the truck simulator, (2) You may find participation in the experiment boring.

The information gathered in this study will permit us to better understand how in-vehicle communication systems effect driver performance. All data obtained is for research purposes only, and will remain confidential. The information will be reviewed by Battelle and the National Highway Traffic Safety Administration (NHTSA) scientists, and the data will reside at Battelle and NHTSA. It is your privilege to withdraw from this study at any time. If you withdraw, you will be paid for the time you have participated without the loss of benefits. For your participation in this study, we will compensate you at the rate of $15.00 per hour. The maximum payment allowed is $60.00. This involves payment at the rate of $15.00 per hour for a maximum of 4 hours of experimental time.

If you have any questions or desire further information about this study, please contact Richard Hanowski or Barry Kantowitz at Battelle, (206) 528-3230.

I have read the attached statement and agree to permit the use of my responses for research purposes.

____________________ __________ __________

Signature of Participant   Date of Birth   Today's Date

____________________ ________________

Please Print Name   Social Security Number

Permanent Mailing Address:________________________

____

____________________ __________

Signature of Investigator   Today's Date

<u>Record of Payment:</u>

_____ hours @ $__.__ per hour = $__.__   Cash/Check __________

TOTAL = $_____

____________________ __________

Signature of Participant   Today's Date

____________________ __________

Signature of Investigator   Today's Date

APPENDIX 6

NHTSA HEAVY VEHICLE SIMULATOR EXPERIMENT
EXPERIMENTER'S PROTOCOL AND INSTRUCTIONS
6/2l/95

RECEPTION

- Meet participants down in the lobby area approximately 10 minutes prior to the time the study should begin.
- Have participants fill out the consent and demographic information forms while waiting.
- Be sure to point out the nearest rest rooms and drinking fountain on the way up to the lab.
- Ask participant to show CDL for verification process.

INSTRUCTIONS

<u>Purpose of Study</u>

Welcome to Battelle's Human Performance Laboratory, The purpose of this study is to better understand how in-vehicle systems may effect driver performance and reduce the occurrence of accidents.

To do this we will ask you to act as a truck driver and drive as safely as you can through a number of pre-designed routes.

You might find some of the routes difficult. Although the data we'll be collecting is for research purposes only, it is very important that you give us your best possible effort. I'd like to assure you that all data collected will remain confidential.

The experiment should last approximately 4 hours. As you have read on your consent form, you may choose not to participate at any time. If you should stop prior to completing all the routes, you will be compensated at the rate of $15.00 per hour. There is a maximum allowable payment of **$60.00.**

You will be paid at the end of the session today. It is important for payment purposes that we have your correct social security number.

Experiment Schedule

You will drive several routes. Each route lasts about 20 minutes. A five minute break will be offered between each route.

Truck Cab Orientation (enter simulator, adjust seat)

This truck simulation was designed to replicate the interior geometry of a Kenworth truck cab. The dimensions you see are all to scale. You will be using the following items in the experiment. Please familiarize yourself with each as I read through the list: starting button, horn, steering wheel, gas pedal, brake, speedometer, tachometer, red dash-mounted clock, radio, text message display, cellular-phone, and the left-side switch on the steering wheel, which I will explain in a moment.

Please press the starting button. You can see the front of the truck, a speedometer, the road and scenery. At different times during your drive, a tone will sound indicating that there is an instruction that you need to read on the text display located on the dash. For example, sometimes the message will instruct you to read the tachometer that is located on the dash behind the steering wheel. At this point, you should read the value indicated on your tachometer (the value will range from one to four). Using the left switch on the steering wheel, indicate the value of the tachometer. Notice that the switch is labeled to remind you. You need to press the switch in the direction of the desired number and release it.

Practice Routes

In a moment, you will begin a practice driving route and then a practice of the in-cab tasks. First, I'd like to explain the types of activities that will occur. In general, all routes in the experiment will simulate actual driving situations. This simulation is equipped with sound effects. You will hear your engine rev and downshift, your wheels will screech if you are going too fast around a corner, and you will hear a crashing sound if you have an accident. You will share the road with other drivers and pedestrians. The other drivers will stay in their lanes. Pedestrians may walk into the street unexpectedly. You may need to stop for pedestrians. There will be curves in the road. In the event of an accident, center the steering wheel and press down on the throttle. The simulator will automatically return the vehicle to the appropriate lane position. At low speeds, steering is difficult. You should try to maintain an approximate speed of 55 miles per hour. In general, the rules that apply in "real life" driving situations apply here as well.

In addition to typical events that occur during driving, there will be 6 other activities that you will have to attend to during some of the routes. Each of these events will be marked by a short beeping sound and will begin with a message and instruction on the text display that is mounted atop of the dash. These activities are as follows:

(1) Check tachometer-- First, as described earlier, sometimes the text display will instruct you to check your tachometer. Use the left-side switch on your

steering wheel to respond.

(2) Check the time-- Second, you may be instructed to check the time. Please look at the clock on the dash and read the time out loud.

(3) Read traffic messages-- Third, the message may instruct you to read a traffic related message out loud.

(4) Tune the radio-- Fourth, you may be instructed to tune the radio to a certain station. The radio is located on top of the dash.

(5) Make a phone call-- Fifth, you will be instructed to make a call on the cellular-phone. The power must be turned off after each phone call. To make a call, turn the power on by depressing the power (pwr) button on the receiver and allow digital readout to clear before placing a call. When using the recall (rcl) button, it is paramount to wait for the number and the Roman numeral to appear on the readout before sending the call. (Demonstrate 528.3286, 206.528.3286, and (rc1)4.)

(6) Watch for pedestrians-- Sixth, some pedestrians will unwisely cross the road in traffic. When you see them do this, use your horn, located in the center of you steering wheel to honk at them. Press fiiy in the center of the horn. DO NOT honk at pedestrians that are simply standing at the side of the road; only honk at those crossing the road.

NOTE: Your first priority is to drive safely. You are the judge for WHEN and IF a non-driving task (e.g., read tachometer) is to be completed.

Do you have any questions about any of the additional tasks?

Would you briefly paraphrase in your own words what you are to do during this session?

Again, your main objective in this practice route and in all the routes is to drive as safely as you can within the specified speed limit.

The practice-drive will last approximately 10 minutes. The practice of the in-cab tasks will last about 5 minutes. I will be sitting behind you throughout the practices and the other test routes.

Do you have any questions?

Please begin the practice driving route by stepping on the accelerator.

- Upon completion of Driving Practice Route begin the text message reading and cellular-phone dialogue practice by pressing the red switch on the experimenter panel.

Are there any questions you would like to ask?

I will not be able to answer any additional questions about the routes or the operation of the truck cab simulation following this time.

Administration of Modules

Drivers	Training		Modules							
8”	Driving	In-Cab Tasks	S3	S4	N3	01’	N4	S4’	S3’	02
8””	Driving	In-Cab Tasks	S4	S3	N4	02’	N3	S3’	S4’	01’

* Odd subject numbers (1, 3, 5, . ..)
** Even subject number (2, 4, 6, . ..)

DEBRIEF

- Give driver debrief questionnaire.
- Ask if he/she has further questions.
- Complete payment form and pay.
- Thank and escort out.

APPENDIX 7

Debriefing Data Collection Form

Questions:

1. Now that we have finished reviewing the driving scenarios. could you describe any strategies that you used while driving the various scenarios.

2. Was there anything about the scenarios or driving simulator that you found particularly difficult or frustrating?

3. Was there any part of the driving simulator that did not seem to function properly?

4. Did you notice any problems with the simulation software while driving the various scenarios?

APPENDIX 8

ANOVA Table 1. Dependent variable = Mean Vehicle Lane Position
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Mean Vehicle Lane Position					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	3.83	3.34	0.091	
Error	13	1.15			
Task Event	**7**	**3.54**	**3.07**	**0.006**	**0.01**
Error	91	1.15			
Density x Task Event	7	0.702	0.71	0.666	0.639
Error	91	0.994			

ANOVA Table 2. Dependent variable = Standard Deviation Vehicle Lane Position
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Standard Deviation Vehicle Lane Position					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.827	1.29	0.276	
Error	13	0.639			
Task Event	**7**	**4.57**	**5.47**	**<.001**	**<.001**
Error	91	0.835			
Density x Task Event	7	0.417	0.86	0.54	0.517
Error	91	0.484			

ANOVA Table 3. Dependent variable = Mean Vehicle Speed
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Mean Vehicle Speed					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**319**	**15**	**0.002**	
Error	13	21.2			
Task Event	**7**	**139**	**3.09**	**0.006**	**0.031**
Error	91	45.1			
Density x Task Event	**7**	**101**	**2.42**	**0.025**	**0.036**
Error	91	41.9			

ANOVA Table 4. Dependent variable = Standard Deviation Vehicle Speed
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Standard Deviation Vehicle Speed					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.789	0.09	0.775	
Error	13	9.25			
Task Event	**7**	**80.3**	**7.3**	**<.001**	**<.001**
Error	91	11			
Density x Task Event	7	13.2	1.37	0.229	0.265
Error	91	9.68			

ANOVA Table 5. Dependent variable = Mean Driver Steering Wheel Rate
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Mean Driver Steering Wheel Rate					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**464**	**25**	**<.001**	
Error	13	18.5			
Task Event	**7**	**71.2**	**2.33**	**0.031**	**0.038**
Error	91	30.5			
Density x Task Event	**7**	**176**	**4.71**	**<.001**	**<.005**
Error	91	37.3			

ANOVA Table 6. Dependent variable = Standard Deviation Driver Steering Wheel Rate
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Standard Deviation Driver Steering Wheel Rate					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	1.62	0.09	0.763	
Error	13	17			
Task Event	**7**	**59**	**3.69**	**0.002**	**0.008**
Error	91	16			
Density x Task Event	**7**	**35.6**	**3.74**	**0.001**	**0.008**
Error	91	8.75			

ANOVA Table 7. Dependent variable = Normalized Lane Exceedance Count
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Normalized Lane Exceedance Count					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.113	0	0.95	
Error	13	27.1			
Task Event	**7**	**79.4**	**4.14**	**<.001**	**0.001**
Error	91	19.2			
Density x Task Event	7	3.33	0.19	0.988	0.988
Error	91	17.8			

ANOVA Table 8. Dependent variable = Peak Lateral Lane Distance
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Peak Lateral Lane Exceedance Distance					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.711	0.18	0.678	
Error	13	3.95			
Task Event	**7**	**46.8**	**6.86**	**<.001**	**<.001**
Error	91	6.82			
Density x Task Event	7	2.87	0.7	0.669	0.633
Error	91	4.08			

ANOVA Table 9. Dependent variable = Peak Longitudianl Lane Distance
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Peak Longitudinal Lane Exceedance Distance					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	5596	0.21	0.655	
Error	13	26672			
Task Event	**7**	**140035**	**7.54**	**<.001**	**<.001**
Error	91	18573			
Density x Task Event	7	27430	2.01	0.063	0.107
Error	91	13664			

ANOVA Table 10. Dependent variable = Percent Crash Occurrence
Independent variables = Traffic Density and
In-cab CRT Text Message Reading Task

Percent Crash Occurrence (0=No Crash, 1=Crash)					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.073	3.14	0.1	
Error	13	0.023			
Task Event	7	0.039	1.14	0.346	0.344
Error	91	0.034			
Density x Task Event	7	0.031	2.02	0.06	0.147
Error	91	0.015			

ANOVA Table 11. Dependent variable = Mean Vehicle Lane Position
Independent variables = Traffic Density and Manual Task

Mean Vehicle Lane Position					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**17.6**	**23.1**	**<.001**	
Error	13	0.768			
Task Event	**4**	**5**	**4.32**	**0.004**	**0.007**
Error	52	1.16			
Density x Task Event	4	1.37	1.92	0.121	0.154
Error	52	0.715			

ANOVA Table 12. Dependent variable = Standard Deviation Vehicle Lane Position
Independent variables = Traffic Density and Manual Task

Standard Deviation Vehicle Lane Position					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**3.68**	**9.61**	**0.008**	
Error	13	0.383			
Task Event	**4**	**9.95**	**15.2**	**<.001**	**<.001**
Error	52	0.655			
Density x Task Event	4	0.911	1.51	0.214	0.214
Error	52	0.604			

ANOVA Table 13. Dependent variable = Mean Vehicle Speed
Independent variables = Traffic Density and Manual Task

Mean Vehicle Speed					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	94.8	3.23	0.095	
Error	13	29.3			
Task Event	4	94.7	1.31	0.277	0.286
Error	52	72.1			
Density x Task Event	**4**	**130**	**3.41**	**0.015**	**0.015**
Error	52	38.2			

ANOVA Table 14. Dependent variable = Standard Deviation Vehicle Speed
Independent variables = Traffic Density and Manual Task

Standard Deviation Vehicle Speed					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	12.3	0.69	0.421	
Error	13	17.8			
Task Event	4	44.4	1.87	0.13	0.161
Error	52	23.7			
Density x Task Event	4	43.4	2.54	0.051	0.073
Error	52	9.68			

ANOVA Table 15. Dependent variable = Mean Driver Steering Wheel Rate
Independent variables = Traffic Density and Manual Task

Mean Driver Steering Wheel Rate					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**355**	**42.2**	**<.001**	
Error	13	8.42			
Task Event	4	1.48	0.1	0.981	0.873
Error	52	14.6			
Density x Task Event	**4**	**204**	**22.4**	**<.001**	**<.001**
Error	52	9.11			

ANOVA Table 16. Dependent variable = Standard Deviation Driver Steering Wheel Rate
Independent variables = Traffic Density and Manual Task

Standard Deviation Driver Steering Wheel Rate					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**51.8**	**6.66**	**0.023**	
Error	13	7.79			
Task Event	**4**	**49.9**	**6.47**	**<.001**	**<.001**
Error	52	7.71			
Density x Task Event	4	0.8	0.07	0.99	0.99
Error	52	10.9			

ANOVA Table 17. Dependent variable = Normalized Lane Exceedance Count
Independent variables = Traffic Density and Manual Task

Normalized Lane Exceedance Count					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	26.4	1.62	0.225	
Error	13	16.3			
Task Event	**4**	**97.7**	**7.23**	**<.001**	**<.001**
Error	52	13.5			
Density x Task Event	4	17.2	1.22	0.315	0.317
Error	52	14.1			

ANOVA Table 18. Dependent variable = Peak Lateral Lane Exceedance Distance
Independent variables = Traffic Density and Manual Task

Peak Lateral Lane Exceedance Distance					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**99.4**	**14.2**	**0.002**	
Error	13	6.98			
Task Event	**4**	**115**	**7.57**	**<.001**	**<.001**
Error	52	15.2			
Density x Task Event	4	14.7	1.38	0.254	0.258
Error	52	10.6			

ANOVA Table 19. Dependent variable = Peak Longitudinal Lane Exceedance Distance
Independent variables = Traffic Density and Manual Task

Peak Longitudinal Lane Exceedance Distance					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**112910**	**7.75**	**0.016**	
Error	13	14563			
Task Event	**4**	**423700**	**9.66**	**<.001**	**<.001**
Error	52	43877			
Density x Task Event	4	27351	1.64	0.179	0.183
Error	52	16701			

ANOVA Table 20. Dependent variable = Percent Crash Occurrence
Independent variables = Traffic Density and Manual Task

Percent Crash Occurrence (0=No Crash, 1=Crash)					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.073	3.14	0.1	
Error	13	0.023			
Task Event	4	0.039	1.14	0.346	0.344
Error	52	0.034			
Density x Task Event	4	0.031	2.02	0.06	0.147
Error	52	0.015			

ANOVA Table 21. Dependent variable = Mean Vehicle Lane Position
Independent variables = Traffic Density and Dialogue Task

Mean Vehicle Lane Position					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.026	0.03	0.856	
Error	13	0.762			
Task Event	**3**	**2.6**	**4.91**	**0.006**	**0.019**
Error	39	0.53			
Density x Task Event	3	0.013	0.06	0.982	0.982
Error	39	0:219			

ANOVA Table 22. Dependent variable = Standard Deviation Vehicle Lane Position
Independent variables = Traffic Density and Dialogue Task

Standard Deviation Vehicle Lane Position					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.085	0.44	0.517	
Error	13	0.191			
Task Event	**3**	**0.531**	**3.77**	**0.018**	**0.031**
Error	39	0.141			
Density x Task Event	3	0.046	0.26	0.852	0.831
Error	39	0.174			

ANOVA Table 23. Dependent variable = Mean Vehicle Speed
Independent variables = Traffic Density and Dialogue Task

Mean Vehicle Speed					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	72.2	0.48	0.5	
Error	13	150			
Task Event	3	253	2.67	0.061	0.1
Error	39	88			
Density x Task Event	3	81.3	0.9	0.451	0.394
Error	39	90.5			

ANOVA Table 24. Dependent variable = Standard Deviation Vehicle Speed
Independent variables = Traffic Density and Dialogue Task

Standard Deviation Vehicle Speed					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.745	0.04	0.854	
Error	13	21.2			
Task Event	3	44.3	2.37	0.086	0.095
Error	39	18.7			
Density x Task Event	3	15.2	0.83	0.488	0.468
Error	39	9.68			

ANOVA Table 25. Dependent variable = Mean Driver Steering Wheel Rate
Independent variables = Traffic Density and Dialogue Task

Mean Driver Steering Wheel Rate					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	**1**	**273**	**30.3**	**<.001**	
Error	13	9.03			
Task Event	3	0.838	0.06	0.983	0.819
Error	39	15.2			
Density x Task Event	**3**	**270**	**25.8**	**<.001**	**<.001**
Error	39	10.5			

ANOVA Table 26. Dependent variable = Standard Deviation Driver Steering Wheel Rate
Independent variables = Traffic Density and Dialogue Task

Standard Deviation Driver Steering Wheel Rate					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	23.4	3.06	0.104	
Error	13	7.67			
Task Event	**3**	**48.2**	**11.3**	**<.001**	**<.001**
Error	39	4.29			
Density x Task Event	3	1.15	0.24	0.871	0.839
Error	39	4.85			

ANOVA Table 27. Dependent variable = Normalized Lane Exceedance Count
Independent variables = Traffic Density and Dialogue Task

Normalized Lane Exceedance Count					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.313	0.03	0.866	
Error	13	10.5			
Task Event	3	9.69	1.05	0.379	0.379
Error	39	9.19			
Density x Task Event	3	1.69	0.18	0.907	0.9
Error	39	9.21			

ANOVA Table 28. Dependent variable = Peak Lateral Lane Exceedance Distance
Independent variables = Traffic Density and Dialogue Task

Peak Lateral Lane Exceedance Distance					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	3.79	1.98	0.183	
Error	13	1.91			
Task Event	**3**	**20.6**	**10**	**<.001**	**<.001**
Error	39	2.05			
Density x Task Event	3	1.46	0.53	0.663	0.561
Error	39	2.75			

ANOVA Table 29. Dependent variable = Peak Longitudinal Lane Exceedance Distance
Independent variables = Traffic Density and Dialogue Task

Peak Longitudinal Lane Exceedance Distance					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	9645	0.52	0.483	
Error	13	18530			
Task Event	**3**	**252240**	**4.97**	**0.005**	**0.005**
Error	39	50581			
Density x Task Event	3	8394	0.7	0.56	0.52
Error	39	12057			

ANOVA Table 30. Dependent variable = Perecent Crash Occurrence
Independent variables = Traffic Density and Dialogue Task

Percent Crash Occurrence (0=No Crash, 1=Crash)					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	<.001	<.001	0.991	
Error	13	0.038			
Task Event	3	0.071	2.17	0.108	0.147
Error	39	0.033			
Density x Task Event	3	0.024	0.67	0.578	0.496
Error	39	0:366			

ANOVA Table 31. Dependent variable = Perecent Object Detection
Independent variables = Traffic Density and Object Detection Task

Object Detection Task					
INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**	**HUYNH-FELDT P**
Density	1	0.009	0.05	0.828	
Error	13	0.182			
Task Event	3	0.057	0.15	0.927	0.912
Error	39	0.371			
Density x Task Event	3	0.033	0.32	0.813	0.813
Error	39	0.103			

ANOVA Table 32. Dependent variable = Response Latency
Independent variables = Traffic Density and Event Response

INDEPENDENT VARIABLE	**DF**	**MS**	**F**	**P**
Mean	1	1598	282	<.001
Density	1	14.2	2.51	0.117
Event Response	1	13.4	2.37	0.127
Density x Event Response	1	4.72	0.83	0.363
Error	95	5.65		

APPENDIX 9

Multiple comparisons using Fisher's LSD. Shaded area indicates significance at .05

Mean Vehicle Lane Position, CRT Text Message Reading Tasks

MEAN		Tach Checking	Time Reading	Radio Tuning	4-Line Reading	Auto-dial	Local-dial	Long-dial
0.73	**Only Drive**							
0.83	**Tach. Checking**							
0.36	**Time Reading**			■	■		■	
1.12	**Radio Tuning**							
1.44	**4-Line Reading**							
0.71	**Auto-dial**							
1.31	**Local-dial**							
0.8	**Long Distance-dial**							

Mean Vehicle Lane Position, Manual Task Event

MEAN		Radio Tuning	Auto-dial	Local-dial	Long-dial
0.73	**Only Drive**	■			
1.78	**Radio Tuning**		■	■	■
0.78	**Auto-dial**				
1.01	**Local-dial**				
1.07	**Long Distance-dial**				

Mean Vehicle Lane Position, Dialogue Task Event

MEAN		Biograpic	Arithmetic	No Questions
0.73	**Only Drive**	■	■	■
1.41	**Biographic**			
1.31	**Arithmetic**			
1.18	**No Questions**			

Standard Deviation Vehicle Lane Position, CRT Text Message Reading Tasks								
MEAN		**Tach Checking**	**Time Reading**	**Radio Tuning**	**4-Line Reading**	**Auto-dial**	**Local-dial**	**Long-dial**
0.891	**Only Drive**							
1.96	**Tach. Checking**							
1.31	**Time Reading**							
2.16	**Radio Tuning**							
1.94	**4-Line Reading**							
1.73	**Auto-dial**							
1.62	**Local-dial**							
1.78	**Long Distance-dial**							

Standard Deviation Vehicle Lane Position, Manual Task Event					
MEAN		**Radio Tuning**	**Auto-dial**	**Local-dial**	**Long-dial**
0.89	**Only Drive**				
2.4	**Radio Tuning**				
2.25	**Auto-dial**				
2.02	**Local-dial**				
2.09	**Long Distance-dial**				

Standard Deviation Vehicle Lane Position, Dialogue Task Event				
MEAN		**Biograpic**	**Arithmetic**	**No Questions**
0.891	**Only Drive**			
0.98	**Biographic**			
1	**Arithmetic**			
1.22	**No Questions**			

Mean Vehicle Speed, CRT Text Message Reading Tasks

MEAN		Tach Checking	Time Reading	Radio Tuning	4-Line Reading	Auto-dial	Local-dial	Long-dial
75.8	**Only Drive**							
74.5	**Tach. Checking**							
70.8	**Time Reading**							
72.7	**Radio Tuning**							
70.3	**4-Line Reading**							
71.8	**Auto-dial**							
69.4	**Local-dial**							
74.3	**Long Distance-dial**							

Standard Deviation Vehicle Speed, CRT Text Message Reading Tasks

MEAN		Tach Checking	Time Reading	Radio Tuning	4-Line Reading	Auto-dial	Local-dial	Long-dial
1.38	**Only Drive**							
1.68	**Tach. Checking**							
1.22	**Time Reading**							
5.31	**Radio Tuning**							
4.15	**4-Line Reading**							
1.38	**Auto-dial**							
4.44	**Local-dial**							
1.5	**Long Distance-dial**							

Standard Deviation Steering Wheel Rate, CRT Text Message Reading Tasks

MEAN		Tach Checking	Time Reading	Radio Tuning	4-Line Reading	Auto-dial	Local-dial	Long-dial
5.97	**Only Drive**							
7.75	**Tach. Checking**							
6.68	**Time Reading**							
9.14	**Radio Tuning**							
9.75	**4-Line Reading**							
9.83	**Auto-dial**							
8.77	**Local-dial**							
9.34	**Long Distance-dial**							

Standard Deviation Steering Wheel Rate, Manual Task Event

MEAN		Radio Tuning	Auto-dial	Local-dial	Long-dial
5.97	**Only Drive**				
9.38	**Radio Tuning**				
8.85	**Auto-dial**				
7.44	**Local-dial**				
8.15	**Long Distance-dial**				

Standard Deviation Steering Wheel Rate, Dialogue Task Event

MEAN		Biograpic	Arithmetic	No Questions
5.97	**Only Drive**			
3.15	**Biographic**			
3.54	**Arithmetic**			
5.03	**No Questions**			

Mean Normalized Exceedance Count, CRT Text Message Reading Tasks

MEAN		Tach Checking	Time Reading	Radio Tuning	4-Line Reading	Auto-dial	Local-dial	Long-dial
2.4	**Only Drive**							
8.11	**Tach. Checking**							
5.16	**Time Reading**							
5.48	**Radio Tuning**							
6.08	**4-Line Reading**							
7.19	**Auto-dial**							
5.96	**Local-dial**							
6.48	**Long Distance-dial**							

Peak Lateral Exceedance Distance, CRT Text Message Reading Tasks

MEAN		Tach Checking	Time Reading	Radio Tuning	4-Line Reading	Auto-dial	Local-dial	Long-dial
0.153	Only Drive							
2.78	Tach. Checking							
0.644	Time Reading							
3.65	Radio Tuning							
3.72	4-Line Reading							
1.82	Auto-dial							
2.19	Local-dial							
1.65	Long Distance-dial							

Peak Lateral Exceedance Distance, Manual Task Event

MEAN		Radio Tuning	Auto-dial	Local-dial	Long-dial
0.153	Only Drive				
5.5	Radio Tuning				
4.26	Auto-dial				
3.17	Local-dial				
4.23	Long Distance-dial				

Peak Lateral Lane Exceedance Distance, Dialogue Task Event

MEAN		Biograpic	Arithmetic	No Questions
0.153	Only Drive			
1.48	Biographic			
2.22	Arithmetic			
1.15	No Questions			