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Heavy Vehicle Driver Workload Assessment
Task 7A: In-Cab Test Message System and Cellular Phone Use by Heavy Vehicle Drivers on the Road

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16. Abstract

This report addresses the application of a workload assessment protocol and measurement system to empirically assess the degree to which a text message and cellular phone system impose workload on heavy vehicle drivers. Sixteen (I 6) professional drivers performed over-the-road driving and various conditions of lighting (dark vs. light), road type (divided vs. undivided), and traffic density (high vs. low). Drivers were asked to read a variety of CRT text messages, to perform several manual tasks, and to respond to several questions imposing cognitive demand. Results revealed that CRT text message impacts visual allocation and lanekeeping and that steering measures were also sensitive to the workload imposed by the CRT messages. Seven- and IO-digit dialing were the manual tasks associated with the highest demand for visual attention, but these tasks did not affect lanekeeping or speed measures. Cellular phone dialogues (cognitive tasks) impacted mirror sampling relative to open road driving. Recommendations for the implementation of the CRT text message system and the cellular phone system in-cab are discussed.

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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, load 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., infrared 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 that device 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". The workload assessment protocol can serve as a draft for such a standard.

This report covers the seventh in a series of tasks involving the assessment of driver workload in heavy vehicle operation associated with in-cab devices or systems. A review of the overall study was provided by Tijerina, Kantowitz, Kiger, and Rockwell (1994). 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. A review of relevant past research is presented next.

1.1.1 Cellular Phone Research

Cellular phones are becoming increasingly common in both cars and trucks. Mobile communications systems, for example, usually include a cellular phone component. There is concern that cellular phone use may increase driver workload to dangerous levels. The available empirical research is scant and often of questionable applicability to the heavy vehicle driver. For this reason, the cellular phone was selected for assessment in Task 7. A review of selected studies of cellular phone use is provided below.

The earliest published study on mobile telephone use and its impact on drivers was that of Brown, Tickner, and Simmonds (1969). They point out that mobile phone use may involve two sources of interference. The first is the manual-visual demands of dialing. The second is the attentional demands of the communications task that ensues. Brown et al. (1969) focussed on the latter only by simulating a hands-free phone application. A sample of 24 male subjects drove a car on a 1.5-mile closed course without traffic to collect measures on judgments of gap size (possible vs. impossible to clear), number of gaps actually cleared successfully, total course travel time (interpreted as speed), and control inputs (steering and foot controls and associated lateral and longitudinal accelerations). The telephone communications task was a paced grammatical reasoning task in which the driver heard a short sentence followed by the letters "A" and "B" where each sentence claimed to describe the order of the letter pair that followed. The driver decided whether the sentence was true or false and responded accordingly. Examples are provided below:

Incoming Phone Message:	Driver (Correct) Response
"A follows B . . . BA"	"True"
" B precedes A . . . AB"	"False"

Results indicated that gap judgements were significantly degraded during telephoning and travel speed was reduced. Additionally, concurrent driving was associated with longer decision times for the grammatical reasoning task and more errors relative to performing the grammatical reasoning task alone while the car was parked. Unfortunately, travel speed was a global measure based on circuit completion time. Thus, it is impossible to tell if drivers drove more slowly throughout the telephoning task or took the additional time driving around incorrectly judged "impossible" gaps.

Drory (1985) reported a simulator study that examined the effects of voice communications on 60 truck driver subjects in the context of a fatigue study. Subjects drove a Redifon light motor vehicle simulator for 7 hr. The voice communication task involved four requests randomly placed during each 15-min interval via a speaker (again a hands-free simulated device) to ask the driver to report current position by reading aloud the last two digits of the odometer. Measures taken included steering wheel reversals, tracking error, number of brake responses to the appearance of tailgate lights during the simulator run, and average brake reaction time, among others. Interestingly, the voice communications task enhanced performance on all driving measures even though it increased subjective assessments of fatigue. This study empirically verified the professional driver's intuition that a concurrent task can break the monotony of driving and help keep the driver awake.

Stein, Parseghian, and Allen (1987) used the STI driving simulator to conduct a study of the effects of cellular mobile phone use on driver performance. Subjects dialed by manually keying in the IO-digit phone number plus an enter key, by recalling a number from memory (i.e., pressing "RCL l" '), or by a voice command (i.e., lift handset and say "TRAVEL AGENT"). Placing a call, the subject driver heard and was required to memorize specific flight information given by a "travel agent"; this information included airline, flight number, originating airport, and destination. On an incoming phone call, the driver had to convey the memorized information. Phone location was an independent variable (dash-mounted, console-mounted) and handset vs. hands-free call receiving method was another independent variable. Results of the study indicated that lanekeeping performance was substantially degraded (i.e., lane standard deviation grew) with manual dialing; this effect was greater for a console mounted phone, and the greatest degradation was for older subjects (i.e., 55 yrs or older). This pattern of effects held on both straight and curve road segments of the simulator scenario. In addition, obstacle detection was degraded with manual dialing. The authors conclude that with the exception of manual dialing, their study results indicate no significant traffic safety problems. They recommended positioning the cellular phone as close as possible to the driver's line of sight, that voice recognition dialing should be encouraged, that memory dialing should be encouraged but drivers should be instructed not to refer to a list of memory codes while driving, and that limiting the number of button pushes while dialing is worth further development.

Zwahlen, Adams, and Schwartz (1988) conducted two experiments in automobiles on an airport runway to investigate the impact of phone dialing on driving. Drivers used a standard push-button phone (to simulate a cellular phone) and manually entered an 1 l-digit number. The experiment varied phone location (high vs. low on the dash), and whether the driver could look at the road while dialing (allowed vs. not allowed). Also drivers did not correct dialing errors. An assessment of lane keeping for straight road driving indicated that manual dialing increased lane standard deviations to potentially dangerous levels. Not being able to look at the roadway ahead while dialing was most disruptive; low-mounted phone position was also disruptive to lane keeping, though much less so than the look/no-look manipulation. When averaged across two different vehicles (a compact passenger car and a station wagon), the standard deviation for lane position was 15.4 in for a 675-ft run. Zwahlen et al. predicts that for a 12-ft wide lane this would lead to lane exceedences under ideal conditions (daylight, dry, straightaway, etc.) 11.9 percent of the time at 40 mph.

Boase, Hannigan, and Porter (1988) investigated the effects of talking while using a hands-free phone (again a simulated device) while the driver was engaged in a laboratory computer game of "squash" that the authors claimed (without rigorous justification) to involve some of the same task demand characteristics as driving. The results are not directly applicable to driving and so will not be discussed here. However, the main telephoning variable was dialogue type. Informational dialogue (ID) was mostly simple question-and-answer dialogues like making appointments, checking dates, and so on; it was mimicked by asking subjects simple questions like their favorite foods or educational experiences. The negotiation dialogue (ND), uncovered in focus groups with businessmen, involved negotiation and deal-making; this was simulated by having subjects engage in a dialogue such as to return faulty merchandise to a store or to replan an airline itinerary altered by the air carrier. This represents an interesting attempt to use dialogues that might arise naturally in mobile or cellular phone use.

Alm and Nilsson (1990) conducted a motion-base driving simulator study of the effects of hands-free mobile phone conversation on driver performance as measured by reaction time, lane position, speed level, and Task Load Index (TLX) subjective workload assessments for easy and hard driving tasks. The "conversation" was actually the Baddeley Working Memory Span Test. A number of 3-to-5-word sentences were presented over the phone of the form "X does Y" and the subject had to answer "YES" if it was reasonable or "NO" if not; For example, one sentence might be "The train bought a newspaper", to which the correct response is "NO"; another sentence might be "The boy brushed his teeth." to which the correct response is "YES" . After 5 sentences, the subject was to recall the last word in each sentence. This telephone task was paced. Results indicated that this telephone conversation had a negative effect on driver brake reaction time and resulted in a reduction in travel speed when the driving task was easy (i.e., mostly straight road segments). It degraded lane position and this was most pronounced when the driving task was hard (i.e., mostly curvy road segments). Finally, subjective workload was always higher with telephone conversation.

McKnight and McKnight (1991) conducted a study of cellular phone use on driver attention using an open-loop simulator that consisted of videotaped road scenes that included

47 situations to which driver might ordinarily respond. These situations included vehicles stopping, turning, and entering a motor way; road changes such as lane drops, narrow bridge, and so forth; pedestrians or animals entering the travel lane; route changes; traffic control signals like stop signs and light changes; etc. As the subject "drove" along the video scene, accelerator pedal use, brake onset, and steering and turn signal use were recorded. The dialing component of the telephone task was to place a call to the subject's home number manually. The conversation component of the telephoning task involved both simple conversations (e.g., gathering demographic information, chit-chat on what the subject did the previous weekend), and complex conversations (i.e., math problems of the form 2+3+4+1/2+3 +4 + 6 = ?) or short term memory problems that required the subject to listen to a list of 5 or 6 digits and then answer whether certain digits were in that list. Results indicated that complex phone conversations led to the greatest increases in missed events and time to respond, followed by a radio tuning task, with simple phone conversation having the least effect. Placing a call did not degrade performance any more than simple conversation but delayed responses about the same as complex conversations. The relative increase in chances of a highway traffic situation going unnoticed ranged from about 20 percent for placing a call to 29 percent for complex conversations. Older drivers (i.e., 50 - 80 yrs) were most adversely affected by telephoning in their ability to detect driving situations. However, time to respond was only affected by age when placing calls.

Brookhuis, De Vries, and De Waard (1991) also examined the impact of telephone use on driver performance in an instrumented passenger car on the road measured every work day for 3 weeks. Twelve subjects drove while and while not operating a mobile telephone under three driving conditions: light traffic, heavy traffic on an outer belt following a confederate lead vehicle, and driving in city traffic. The dialing component was either manual or hands-free, and the telephone conversation consisted of a 3-minute test, presented over the phone, of a paced serial addition task that was a fairly hard combination of a memory test and an addition test. Results indicated a variety of interesting patterns. There was a decrease in lane standard deviation while in telephone conversation, particularly while driving on a quiet motorway. Steering wheel amplitudes were substantially higher with manual dialing. There was a decrease in the number of rearview mirror checks during conversation, but only on the quiet motorway. There was a statistically significant increase in brake reaction time while telephoning of about 600 ms to adapt to a slowing lead vehicle and a non-significant increase of about 130 ms to brake for a stopping lead vehicle (i.e., lead vehicle brake lights suddenly come on). However, drivers did not decrease their average travel speed (termed speed coherence in the paper), and this compounded with the greater reaction times could lead to an increase in rear-end collision hazards. This is a similar result to that found by Alm and Nilsson (as described by Parkes, 1993) in which drivers in an instrumented vehicle had longer choice reaction times while telephoning; this was especially true for older drivers. The increase was on average about 1.5 s higher while telephoning than while not telephoning but subjects did not compensate by increasing their headway during the carphone conversation.

Parkes (1993) summarized a series of studies of voice communications (cellular phone) use conducted in England as part of the PROMETHEUS program. Of these, two on-the-road studies with automobiles are of particular interest. Fairclough et al. (as summarized by Parkes, 1993) compared carphone use with speaking to a passenger while the driver drove on an open roadway. Driving behavior was measured in terms of route completion time, eye movement behavior, heart rate, and subjective workload assessments. Roth speaking conditions resulted in higher subjective workload assessments and longer route completion times as a consequence of reducing travel speed about 10 percent in the mixed urban and rural route. No differences in driver visual allocations were noted. Heart rate was significantly higher while using a carphone than while speaking to a passenger directly or driving with no speaking. Unfortunately, the nature of the communications task was not explicitly described but it may have involved a battery of seven mental tests that included numerical and verbal memory, simple arithmetic, numerical reasoning, inference, deduction, and interpretation of short paragraphs.

Parkes et al. (as summarized in Parkes, 1993) also conducted an on-the-road study in "low complexity driving" using a three-lane motorway with moderate traffic flow. Subjects drove two 20- minute journeys, one in silence, and one involving four conversations. These communications involved mental arithmetic and memory tasks. Driving behavior was measured in terms of accelerator depression, steering wheel reversals, and travel speed. Subjective workload assessments were collected by means of the Modified Cooper-Harper Scale and the TLX. Finally, global observations by a ride-along experimenter included recordings of the number of lane changes, overtaking behavior, and proportion of time spent in each of the three lanes. Results indicated no evidence of change in driving behavior during phone conversations. Speed choices, lane occupancy, and accelerator depressions were consistent across all experimental conditions. Subjective workload assessments did reveal an increase in perceived workload. The duration of conversations was limited to 2 minutes only, however, and Parkes et al. note that longer calls might involve a greater demand on driver resources.

Serafin, Wen, Paelke, and Green (1993) have reported on a car simulator study of mobile phone usability in terms of features such as manual vs. voice dialing, instrument panel vs. head-up (HUD) displays, length of phone number (7 vs. 11 digits) and number familiarity (unfamiliar vs. previously memorized). The communications tasks included loose ends (how many unconnected ends are there in a capital letter), listing (name as many items in a category as possible in a fixed time period, e.g., "a type of furniture") , talking (answer the question "What did you do last weekend?"), and listening (i.e., listen to a hypothetical situation and answer multiple choice questions about it). Each task lasted about 30 s and all test participants were given the same materials. The driving simulator run simulated a night drive on a single lane, slightly curvy road; the dependent driving measure was standard deviation of lane position. In terms of driving performance, lane standard deviation was greater with dialing. In terms of dialing performance, voice input resulted in less lane position deviation for all drivers and faster dialing times for older drivers dialing unfamiliar numbers.

Most recently, Pachiaudi and Chapon (1994) reported some results of research into cellular car phone use on a car simulator conducted in France. The nature of the car phone communications task was not described but the simulator scenario was a simple route for which drivers were to try to maintain constant speed (either 90 or 130 kph). Of the 17 subjects in the study, only two showed no change in travel speed while telephoning. For nine subjects, telephoning caused them to modify their travel speed (slow down) while for the other subjects, speed control was momentarily lost and this led to increased speed variability or increase in speed without attempts to correct for this.

The following general remarks can be drawn from the review. First, virtually no studies have used heavy vehicle drivers. These drivers, when compared to passenger car drivers, have more time on the road, are more accustomed to using voice communications (in the form of a CB radio), and may therefore be better able to manage voice communications tasks concurrent with driving. Second, no on-the-road studies have been conducted in a heavy vehicle. Given the wider berth of the heavy vehicle and its more demanding control characteristics, the driver-vehicle performance may be more sensitive to workload demands than in a passenger car. Third, there has been no systematic investigation of cellular phone use in driving conditions that varied by traffic density, road type, and ambient lighting. Fourth, the studies have often used artificial communications tasks, especially to induce high workload. The main benefit of using artificial communications is that they do provide a common measurable basis for comparison. Furthermore, if it is remembered that the objective of Task 7 is to assess the sensitivity of driver workload measures and methods, then the use of artificial communications is probably acceptable. These points suggest that cellular phone use on-the-road in a heavy vehicle under various driving conditions would be a sound choice for inclusion in Task 7.

1.1.2 Text Message Display Research

No studies were found that addressed text messaging per se in an automotive application. However, the human factors literature contains many studies of textual display factors that impact visual search and reading (cf., Boff, Kaufman, and Thomas, 1986). These factors include physical display parameters such as display luminance, display contrast, and polarity. They also include typographic parameters such as type font, size, intercharacter spacing, and interline spacing. Content-related factors such as line length, number of lines, and word frequency also impact visual search and reading performance. Finally, human reading performance is affected by cognitive demands of written comprehension, as evidenced by the many comprehension tests available (e.g., Carroll, 1993). Any or all of these effects can have a substantial impact on driver visual allocation, attention, and subsequent driver-vehicle performance. For this reason, text message displays merit further investigation. This is especially true in light of the substantial alphanumeric and textual display capacity available in mobile communications systems and in forthcoming Advanced Traveler's Information

System (ATIS) applications. For this reason, a text message display application was chosen for inclusion in the Task 7 study.

1.2 Objective

The objective of the Task 7 research was to apply the workload assessment protocol and measurement system to the selected technologies and determine characteristics and conditions of implementing those technologies that can have undesirable safety consequences. The results of the device use would be compared to baseline workload measures taken to provide indications of the driving conditions and device characteristics under which it would be safe to use or operate the technologies.

1.3 Organization of the Report

The remainder of this report is organized into several separate sections. Section 2.0 provides a detailed description of the protocol used, test participants, test vehicle, driving conditions (e.g., lighting condition, road type), and in-cab task conditions. Subsequent sections provide a description of the dependent measures, statistical analyses carried out on those dependent measures, and the statistically significant results obtained. There are separate results sections for text message display use (emphasizing visual demand), for cellular phone dialing and a baseline of radio tuning (emphasizing visual-manual demand), and for cognitive tasks characterized by biographic question-and-answer dialogue, arithmetic question-and-answer dialogue, and open-road driving as a baseline. The report concludes with discussion of the results as a whole. Appendices are provided that contain additional details of the procedures and materials used, as well as additional details of the results obtained.

2.0 METHODOLOGY

2.1 Approach

2.1.1 Test Participants

Sixteen (16) professional heavy vehicle drivers, between 32 and 60 years of age (mean age of 47.2 years), with between 6 and 35 years of experience driving trucks with long trailers (mean of 2 1.6 years), participated in the study. Seven of the 16 test participants had some prior experience with cellular phones but none could be considered regular cellular phone users. All drivers had a current commercial driver's license (CDL), no more than three moving violations and/or one "at fault' accident within the last three years, and no Driving Under the Influence (DUI) violations within the last three years. With one exception, all subjects were drawn from the subjects used in the Task 6 baseline study reported in Rockwell et al. (1995).

2.1.2 Test Vehicle, Text Display, and Cellular Phone

The truck used in Task 7, identical to that used in Task 6, consisted of a 1992 Volvo/White GMC, conventional tractor with sleeper compartment and a 53 foot, 1993 Fruehauf dry freight van semi trailer. The trailer was loaded with ballast to bring the gross vehicle weight to 76,300 pounds. The tractor was equipped with standard engine gauges, tachometer, speedometer, CB radio and an AM/FM stereo radio.

The text message display consisted of a 7-inch diagonal VGA-compatible green-phosphor CRT set to display bright characters (Courier type font, 16-18 arc minutes when viewed from 32-36 inches) on a dark background. The display was mounted on the top of the instrument panel to the right of the seated driver. A hood was mounted around the display to control for glare. Messages were presented by a ride-along experimenter from a laptop PC with an external VGA connector between the PC and the CRT. A buzzer sounded for 1 second when a text message arrived at the CRT.

A black cellular phone (Motorola Model No. 19017NAABB) was installed to the right of the seated driver and included a recall (RCL) feature to dial stored numbers. Manual dialing was completed by pressing a SEND button.

2.2 Instrumentation: Video Recording System, Sensors, and Data Capture System

The truck used in this study was instrumented with a variety of equipment to capture driver behavior and driver-vehicle performance. The captured data were in two different forms: video data and engineering data. These two forms provide a convenient means to organize the instrumentation description.

2.2.1 Video Recording System

The tractor was equipped with a video system to record the events of the run for post-run data reduction. The recording system consisted of four video cameras, two video cassette recorders (VCRs), monitor, video switcher, a time code generator and a four-into-one video "splitter."

One camera was mounted to the ceiling of the cab and directed toward the driver's face. This view of the driver was used to record the subject's visual glances during the run. Two cameras were mounted on the front wheel fenders of the truck (one on each side) and directed toward the road ahead of the truck. These two cameras were used to monitor traffic and road conditions as well as to record the lane selection of the subject throughout the run. A fourth camera was mounted inside the cab and aimed to record distance headway information displayed by a headway measurement device or the hand activity on the steering wheel as desired.

A time base for post-run data analysis was provided using a video time code generator. The time information output by this device was superimposed on the view of the subject's face prior to recording on the VCRs. The time code generator provided a high-speed elapsed time clock with resolution of 1/3Oth second (one video frame).

The scenes from the four cameras were recorded on two VCRs. One recorder contained the view of the subject's face. The second VCR contained a split-screen view of the scenes from all four cameras. Since the time code information was superimposed on the view of the subject's face, a common time base was established on the recordings for both VCRs.

The video monitor and switcher permitted the experimenter to periodically view each video recording to ensure proper camera aim following in-route seat adjustments or postural changes made by the subject.

2.2.2 Video Data Reduction

The videotapes were examined by a data reducer to obtain the visual allocation data for the selected periods of natural, i.e., unprompted driving and for the periods where the driver was given in-cab tasks to perform.

In reducing the visual data, a glance was defined as one or more eye fixations to a specific location. A glance began when the driver's eyes first began to move away from the road scene to a specific location and ended when the eyes either returned to the road scene or to another location. The high speed clock superimposed on the video was used to determine the start and stop times associated with a glance. The following categories, after calibration, were available to classify the driver's glance locations:

a. Road
b. Right Side Mirror
c. Left Side Mirror
d. Instrument Panel
e. In-Cab Device (either CRT, phone or radio)
f. Other (CB radio, left and right side windows)

The Road category refers to glances to the road scene directly ahead of the truck (the normal driving location) and also those few glances to the road scene to the forward right or forward left but not directly ahead of the truck. Such glances might be used to monitor traffic in adjacent lanes or along the shoulder of the road. The Right Side and Left Side Mirrors refer to glances to the West Coast side mirrors on the truck. Note also that a distinction can be made between glances to the instrument panel and any in-cab device under evaluation. This was made possible because the in-cab device was situated in a unique location that permitted glances to the device to be resolved from other locations in the driver's view.

The Manual activity data reduction involved ascertaining the frequency and duration of hands off the steering wheel to complete the digit dialing tasks and hold the phone for answering required questions. Steering wheel hand usage for normal driving was secured over a 2-minute segment of natural driving.

2.2.3 Engineering Data Capture System

A suite of sensors was used to capture driver in-cab behavior, speed and headway maintenance, and lanekeeping performance. All measures were taken at a sampling rate equal to the video frame rate of 30 samples per second. Given the recording of the time stamp provided by the time code generator, this sampling rate allowed for correlation of the video data and the engineering data. The sensor suite used in the vehicle is provided in Table 2.2.1.

Table 2.2.1 Engineering Data Capture Instrumentation for Measures used in Task 6 Baseline Study

Fundamental Measurement	Instrumentation
Steering Wheel Angle	String potentiometer in the engine compartment attached to the pitman arm and a redundant potentiometer mounted under the dash board inside the cab.
Steering Wheel Velocity	A tachometer (DC motor) attached to the steering wheel position string potentiometer.
Accelerator Position	Potentiometer calibrated to generate 0% to 100% of throw.
Travel Speed	A 5th wheel tachometer. Also a redundant channel available in car following situations from a forward-looking radar processing system.
Acceleration (lateral, longitudinal, yaw rate)	Lateral, longitudinal, and yaw rate accelerometers mounted near the center of gravity of the cab.
Headway Distance	Infrared laser range finder system with maximum range of 250 meters.
Headway Relative Velocity	Forward looking Doppler radar system.
Lane position	Optical lane tracker that sensed the luminance difference between a lane line and the surrounding pavement. Auxiliary lighting of the lane tracker field-of-view was used for night driving segments.
Data Acquisition System	182-channel data acquisition and storage system. For every sample, the time stamp generated by the time code generator was recorded both on the video image and as a channel of the data acquisition system. All engineering data stored on a high-density tape cartridge.

Data reduction involved filtering by means of custom software developed by the NHTSA Vehicle Research and Test Center (VRTC) in East Liberty, OH. After all data channels to be analyzed had been filtered as deemed appropriate by VRTC personnel, data reduction moved to extracting those portions of the data stream correlated with the units of observation to be analyzed. This process used the begin and end time codes provided from the video data reduction process. For example, if the unit of observation was 60 seconds of open road driving for a given test participant, the begin time code and the end time code were provided from the video data reduction. Since those codes were recorded as part of the engineering data stream, this allowed for accurate extraction of the relevant portion of the data stream for analysis purposes. Note that the headway measurements taken in this study were too sparse in number and contained a lot of noise; therefore, these measurements were not used in the study.

2.3 Test Route

The test route was arranged to encompass variations in lighting (dark vs. light), road type (divided vs. undivided), and traffic density (high vs. low). Test participants were placed into two groups (AM and PM groups) and the driving condition combinations given in Table 2.3.1 were planned. The route was essentially a 4-hour run in the vicinity of Columbus, Ohio, starting at the Roadway Trucking terminal on Frank Road and I-71 and travelling south on I-71 to I-270, proceeding east and then north on I-270 to SR- 161, east on SR-161 to Granville, west on SR-161 to I-270, then south and west on I-270 to I-71 (See map in Appendix A). The route was replicated so that four segments were obtained according to the sequences provided in Table 2.3.1. Note that the divided road type was a 4- to 6-lane urban freeway. The undivided road type was a 2-lane highway.

Route selection and scheduled departure times were the means used to attempt to insure required light and traffic levels. Uncontrollable variations in traffic density and lighting conditions (caused by late starts, traffic delays, or weather interference) sometimes led to data loss or reclassification. Periods of normal driving (open-road) without in-vehicle tasks were also recorded. Each driving condition phase occurred over roughly a 10 to 15 minute period, about one each hour of the 4-hour run. Thus, data collection periods were separated in time.

2.4 Test Materials

Table 2.4.1 contains examples of text message test materials. These types of messages were presented one at a time according to a presentation schedule followed by the ride-along observer. They were implemented on a laptop PC which was used by the ride-along observer to present messages, along with an auditory tone (buzzer) that sounded for 1 second upon presentation of the message on the text display. In this way, the ride-along observer had discretion, based on driving conditions to determine when best to present the messages (or not

Table 2.3.1 Driving Condition Factor Combinations

AM Test Participant (N=8) Driving Condition Phases:			
Route	**Lighting**	**Road Type**	**Traffic**
I-270 (NE)	Dark	Divided	Light
SR-161 (EB)	Dark	Undivided	Heavy
I-270 (NE)	Light	Divided	Heavy
SR-161 (EB)	Light	Undivided	Light
PM Test Participant (N=8) Driving Condition Phases:			
I-270 (NE)	Light	Divided	Light
SR-161 (EB)	Light	Undivided	Heavy
I-270 (NE)	Dark	Divided	Heavy
SR-161 (EB)	Dark	Undivided	Light

Note: EB = East-bound: NE = Northeast-bound

Table 2.4.1 Example Text Message (CRT) Test Materials

Message Number	Message Content
Message No. 1	What is the current air pressure?
Message No. 2	What is the current time?
Message No. 3	Possssible delay at I-270 and Morse Rd. For details, tune radio to FM 90.5.
Message No. 4	Please read this message out loud.. . Expect delays on I-270 northbound at Morse Road for next hour due to traffic accident in right lane.
Message No. 5	Voice-Dial the home office.
Message No. 6	Auto-Dial with RCL 1.
Message No. 7	Dial 424-5406 for questions.
Message No. 8	Dial 614-424-2075 for questions.

present them in terms of safety constraints). Across the four driving segments, message content was varied slightly, e.g., different phone numbers were used.

Example question-and-answer dialogue materials, recorded on Battelle's ASPEN voice answering system, are given in Table 2.4.2. The ASPEN system presented paced, pre-recorded questions and recorded the driver's verbal response. During each of the four driving condition phases a driver experienced, eight text messages (see above) and the two dialogue types were presented. Thus, four sets of materials were prepared. Across the four driving condition phases or segments, dialogue message content was varied slightly. Also, there were only two dialogues within a driving phase. So, two of the four dials concluded with the driver hearing "Thank you for calling. You may now hang up. Good-bye." The order for these dialogue events is presented in Table 2.4.3.

2.5 Procedure

At the start of a session, a driver signed an informed consent form (See Appendix B), checked out the vehicle, and reviewed and practiced with the text message and cellular phone systems. The vehicle was then taken out along a prescribed route with an on-board experimenter present in the vehicle at all times. During a particular phase of the drive, various in-cab tasks were completed. At the end of the data collection run, the driver was debriefed and paid for the test participation. See Appendix C for subject instructions.

2.6 Experimental Design

Separate analyses were conducted for each of the following three task data sets: Visual (CRT) Task data (8 different text messages); Manual Task data (auto-dial, 7-digit, and lo-digit manual cellular phone dialing, plus radio tuning as a control condition) data; and Cognitive Task data (the two question-and-answer dialogue tasks with open-road driving as a control condition). Each analysis used a four-factor (Task, Lighting, Road type, Traffic) plus Subjects repeated measures Analysis of Variance (ANOVA), with deliberate confounding between Groups and the Lighting x Road type x Traffic interaction. Data transforms (e.g., log transform) were used to stabilize variances and normalize the data prior to analysis. A significance level of $a = 0.05$ was used throughout. Data loss occasionally occurred for reasons that ranged from instrumentation malfunction to 'run-out', a term used by the project staff to indicate a phase of the data collection run where planned nominal driving conditions changed or literally ran out (of traffic, or a particular road type, etc.).

Note that "Traffic" was derived from videotapes of the forward facing cameras which showed the number of vehicles in the driver's field of view and the headway meter. Criteria for high traffic are included in Appendix D.

Table 2.4.2 Example Question-and-Answer (Q&A) Dialogues

Biographical Q&A (Low Wnrkload Anticipated):

"Hello. Please state your full name." < 7 s pause >

"What is your date of birth?" < 7 s pause>

"What is your current age?" <7 s pause>

"What is your place of birth?" < 7 s pause >

"What is your current address?" < 7 s pause >

"In what states, other than Ohio, have you lived?" <7 s pause>

"Thank you for the information. You may now hang up. Good-bye."

Arithmetic Q&A (Moderate Workload anticipated):

"Hello. Please state your full name." < 7 s pause >

"Please answer the following questions." < 5 s pause >

"How long have you been driving today?" < 10 s pause>

"How much longer can you drive today before you reach the [hours of service] limit?" <10 s pause>

"How long will it take to make a 400-mile run if you average 40 miles per hour?" < 10 s pause>

"How many gallons of fuel are needed to drive 350 miles?" < 10 s pause>

"How many miles will you travel in two-and-a-half hours if you average 50 miles per hour?" < 10 s pause >

"Thank you for your answers. You may now hang up. Good-bye."

Table 2.4.3 Order of Dialogue Types by Driving Segment

	Driving Segment			
	Segment 1	**Segment 2**	**Segment 3**	**Segment 4**
	Biographical	Arithmetic	No Conversation	Arithmetic
	Arithmetic	No Conversation	No Conversation	No Conversation
	No Conversation	No Conversation	Biographical	Biographical
	No Conversation	Biographical	Arithmetic	No Conversation

Notes:

1. Biographical = Biographical Question-and-Answer dialogue
   Arithmetic = Arithmetic Question-and-Answer dialogue (i.e., mental arithmetic)
   No Conversation No Conversation - Hang Up Phone after dialing.

2. The sequence within a column represents the order of dialogue types that a test participant experienced within a single driving segment given that four cellular phone dialing tasks were executed.

2.7 Dependent Measures

Four classes of dependent measures were evaluated in separate univariate repeated-measures ANOVAS. These were: visual allocation measures, driver steering and accelerator pedal measures, driver-vehicle performance in terms of speed measures and driver-vehicle performance in terms of lanekeeping measures. Definitions for these categories of dependent measures are provided below.

The dependent measures used to characterize heavy vehicle driver visual allocation are provided below. All times are given in seconds; fractions are given as proportions.

- Mean time off-road (MTOR); this is the average single-glance duration spent looking away from the forward driving scene (i.e., straight ahead, forward left hand side, and forward right hand side viewing locations).

- Mean on-road time (MORT); this is the average single-glance duration spent looking at the forward driving scene.

- Mean mirror glance duration to both side mirrors (MM); this is the average single-glance duration spent sampling the mirrors, averaged over both left and right mirrors.

- Mean left mirror glance duration (MLM); this is the average single-glance duration spent looking at the left mirror.

- Mean right mirror glance duration (MRM); this is the average single-glance duration spent looking at the right mirror.

- Mean instrument panel duration (MIP); this is the average single-glance duration spent head down in the cab of the heavy vehicle looking in the direction of the instrument panel.

- Fraction of time allocated to mirrors (FRACM); this is a proportion of the total measurement interval spent looking at the mirrors. It is the sum of the individual glance durations to the mirrors over the measurement interval of time.

- Device Average Glance Duration (DGLNCAV); this is the mean single glance dwell time to a particular device (radio, CB, mirror, etc.), associated with a requested task.

- Device number of glances (DGLNCNUM); this is the number of glances to a particular device to complete a requested task.

- Total Time to Device (DGLNCTOT); The total time spent looking at a particular device to complete a requested task.

- Road glance average duration (RGLNCAV); the mean single-glance duration spent looking back at the road scene (i.e., scanning the road scene) while completing a particular requested task.

- Total requested task duration (TOTDUR); the total time to complete a requested task, measured from the first glance (in the case of visual-only tasks) or the first gesture (in the case of manual or visual-manual tasks), whichever came first.

The following dependent measures were collected and analyzed to capture steering inputs:

- Steering Wheel Position Variance, degrees^2 ; The sample variance of steering wheel angle over a given sample time interval

- Steering Wheel Velocity Variance, [degrees/s]*; The sample variance of steering velocity over a sample time interval

- Steering Holds, count; A steering hold was defined to occur when the steering wheel velocity is zero for a minimum of 400 ms.

- Steering Reversals, count; A steering reversal was defined to begin when the steering velocity left a zero-velocity dead band and ended when the steering velocity entered a zero-velocity dead band such that the magnitude of the reversals was 2 degrees or greater.

The following dependent measures were collected and analyzed to capture accelerator and brake inputs:

- Accelerator Pedal Position Variance, percent^2 ; The sample variance of accelerator pedal percent of throw (0 for pedal released to 100 percent for pedal to the floor) over a given sample time interval

- Accelerator Pedal Velocity Variance', [percent of throw/s]2; — The sample variance of accelerator pedal velocity over a sample time interval

- Accelerator Holds, count; — An accelerator hold was defined to occur when the accelerator pedal velocity was zero for a minimum of 400 ms.

- Accelerator Releases, count; — An accelerator release was defined to occur when the accelerator pedal was in the null (zero percent) position for a minimum of 400 ms.

The following dependent measures were collected and analyzed with respect to travel speed:

- Mean Speed: — The arithmetic average travel speed for a particular sample interval of time, m/s

- Speed variance: — The sample variance of travel speed computed for a particular sample interval of time, [m/s]*

The following lanekeeping dependent measures were collected and analyzed:

- Mean Lane Position (LANEPOSM), meters from lane center; — The arithmetic average of lane position with respect to lane center over a sample interval of time. Lane position left of lane center is positive in sign and lane position right of lane center is negative in sign.

- Lane position variance (LANEPVAR), m^2 — The sample variance computed for all lane position values in a sample interval of time.

- Lane exceedences, count (LANEXC); — A lane exceedence occurred whenever any portion of the heavy vehicle exceeded a lane boundary line.

3.0 RESULTS: CRT READING TASK

3.1 CRT Text Message Reading Effects

Table 3.1.1 presents the significant effects of CRT message type on the dependent measures collected. The CRT message numbers correspond to those given in Table 2.4.1. Device (CRT) average single glance durations were not significantly different (M = 1.56 s, overall), indicating that drivers on average took their eyes off the road for only a narrow range of (short) glance durations. On the other hand, number of glances to the CRT were significantly different as a function of message type. The average number of glances to the CRT was greater to the 2-line displays (M = 4.58 glances) and 4-line displays (M = 7.38 glances) than to the l-line displays (Means between 1.14 and 2.01 glances), indicating greater workload. Average single glance durations to the road scene during CRT reading were significantly different as a function of message type. Mean road glance durations were shorter for the l-line air pressure and time messages (0.47 and 0.60 s, respectively), perhaps because they were accomplished in between one and two glances, on average. However, the mean road glance durations during the 2-line and 4-line text messages were shorter (M = 0.67 s for each) coincident with a greater number of glances away from the road scene, indicating the driver was shortening visual scanning of the road scene somewhat as compared to the other l-line messages (means of between 0.83 s and 0.95 s for the dialing messages). Total glance time to the CRT and total task duration were also significantly different across the different message types. As indicated in Table 3.1.1, the 2-line radio tuning message and 4-line message were, on average, those that took eyes off the roadway the longest and took the longest to complete.

Two steering measures that might be sensitive to driver workload are steering holds and steering reversals (Tijerina, Kiger, Rockwell, and Wierwille, 1995). With increased attentional demand away from the driving task, steering holds (defined as periods of 0.4 s or greater where the steering velocity is zero) might increase. Steering reversals (defined as the number of times that steering velocity passes through zero and changes sign, with a steering position change of 2 degrees or more) might decrease with decreased attention to the driving task. Logic similar to that applied to steering holds can also be applied to accelerator pedal holds. Accelerator pedal releases might increase if the driver adopts the strategy to take the foot off the accelerator and coast while engaged in the in-vehicle task.

For CRT reading, steering holds were not statistically significantly different. Steering reversals were significantly different ($p < .000l$), with more reversals on average during the 2-line messages (M = 12.08 reversals) and the 4-line messages (M= 17.67 reversals) than for the l-line messages (means ranging from 3.95 to 7.12 reversals). More steering reversals tend to occur with longer duration tasks.

Table 3.1.1 Significant Effects of CRT Text Message Number on Workload Measures During CRT Text Message Reading

Dependent Measures	CRT Message Type							
	1-Line Air Pressure Message	1-Line Time Message	2-Line Radio Message	4-Line Reading Message	1-Line Voice Dial Message	1-Line Auto-Dial Message	1-Line 7-Digit Dial Message	1-Line 10-Digit Dial Message
Number of Glances to CRT[a]	1.14 (0.5)*	1.21 (0.45)	4.58 (1.96)	7.38 (2.73)	2.01 (1.31)	1.43 (0.62)	1.81 (0.91)	1.86 (0.9)
Road Glance Average Duration[b]	0.47 (0.28)	0.60 (0.78)	0.68 (0.34)	0.66 (0.4)	0.96 (0.99)	0.85 (1.07)	0.95 (1.21)	0.83 (0.95)
Total Glance Time to CRT[c]	1.69 (0.71)	1.58 (0.45)	6.44 (2.06)	10.68 (2.84)	2.44 (1.38)	2.10 (0.93)	2.46 (1.28)	2.60 (1.21)
Device Average Glance Duration[d]	1.53 (0.53)	1.40 (0.44)	1.66 (0.98)	1.71 (1.32)	1.35 (0.5)	1.57 (0.77)	1.41 (0.52)	1.50 (0.58)
Task Total Duration[e]	4.56 (2.18)	3.73 (1.65)	10.68 (6.42)	15.51 (5.08)	5.92 (3.74)	3.50 (2.41)	5.40 (7.88)	4.99 (5.16)
Steering Position Variance[f]	39.87 (39.18)	39.16 (35.60)	44.28 (24.13)	50.67 (27.10)	27.78 (27.04)	31.00 (25.60)	36.70 (35.90)	29.96 (26.37)
Number of Steering Holds[g]	0.26 (0.60)	0.25 (0.51)	0.40 (0.76)	0.54 (1.13)	0.41 (0.84)	0.15 (0.41)	0.30 (0.60)	0.32 (0.65)
Number of Steering Reversals[h]	4.96 (2.95)	3.95 (2.51)	12.08 (8.06)	17.66 (6.40)	7.12 (5.13)	4.12 (3.30)	5.92 (10.06)	5.85 (6.54)
Accelerator Position Variance[i]	0.007 (0.01)	0.007 (0.01)	0.01 (0.02)	0.02 (0.04)	0.007 (0.01)	0.006 (0.01)	0.004 (0.08)	0.01 (0.03)
Number of Accelerator Holds[j]	1.64 (1.21)	1.32 (0.62)	3.24 (2.02)	4.19 (2.64)	1.93 (1.18)	1.39 (1.21)	1.68 (2.19)	1.41 (0.70)
Mean Speed[k]	22.61 (2.13)	21.33 (3.20)	22.00 (2.62)	22.28 (2.01)	22.13 (2.27)	22.11 (0.75)	21.90 (2.23)	22.30 (1.76)
Variance of Speed[l]	0.01 (0.04)	0.01 (0.05)	0.38 (2.26)	0.14 (0.37)	0.03 (0.06)	0.01 (0.02)	0.05 (0.20)	0.04 (0.18)
Lane Position Variance[m]	0.007 (0.01)	0.006 (0.02)	0.01 (0.02)	0.02 (0.04)	0.007 (0.01)	0.006 (0.01)	0.004 (0.008)	0.01 (0.03)

Table 3.1.1 Effects of CRT Text Message Number on Workload Measures During CRT Text Message Reading (Continued)

Dependent Measures	CRT Message Type							
	1-Line Air Pressure Message	1-Line Time Message	2-Line Radio Message	4-Line Reading Message	1-Line Voice Dial Message	1-Line Auto-Dial Message	1-Line 7-Digit Dial Message	1-Line 10-Digit Dial Message
Number of Lane Exceedences[n]	0.14 (0.35)	0.14 (0.35)	0.17 (0.42)	0.38 (0.68)	0.17 (0.38)	0.16 (0.36)	0.13 (0.34)	0.25 (0.47)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(7, 409) = 155.78, p = .0001$
b. $F(7, 409) = 4.30, p = .0001$
c. $F(7, 409) = 305.05, p = .0001$
d. Not statistically significant.
e. $F(7, 409) = 55.49, p = .0001$
f. $F(7, 409) = 6.04, p = .0001$
g. Not statistically significant.
h. $F(7, 409) = 53.14, p = .0001$
I. $F(7, 409) = 8.43, p = .0001$
j. $F(7, 409) = 29.16, p = .0001$
k. $F(7, 409) = 2.21, p = .0329$
l. $F(7, 409) = 2.51, p = .0155$
m. $F(7, 409) = 5.03, p = .0001$
n. $F(7, 409) = 2.77, p = .0079$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Steering position variance was also significantly affected by message type, with greater steering variability associated with the 2-line and 4-line messages. The lack of steering holds and pattern of steering reversals and steering variability observed suggests no effect of CRT message type of heavy vehicle driver steering behavior.

Accelerator pedal releases were not significantly different across CRT message types. Accelerator pedal holds were statistically different ($p < .0001$), occurring more frequently during the 2-line and 4-line messages (means of 3.24 and 4.19 holds, respectively) than during the l-line messages (means ranging from 1.32 to 1.93 holds). Thus, there appears to be some indication of decreased accelerator inputs while engaged in more demanding CRT reading *tasks.*

Speed control and lanekeeping might degrade with high attentional demand away from the driving task (Tijerina et al., 1995). For CRT reading, message type had no substantial effect on average speed, though there was a statistically significant effect. The mean was close to 22 m/s across all message reading tasks. Speed variance was statistically significant, with the greatest variability associated with the 2-line and 4-line messages. However, even these effects appear to be of no practical significance.

Lane position variance and number of lane exceedences were reliably different as a function of message type. Converting to meters for convenience, the mean lane position standard deviations were 0.084, 0.082, 0.118, 0.160, 0.085, 0.082, 0.064, and 0.109 m for messages 1 through 8, respectively. Lane exceedences follow a similar trend; the mean number of lane exceedences was greatest for the 4-line message, indicative of attentional demand. For reference, there were a total of (9, 9, 10, 17, 10, 9, 7, and 14 exceedences for messages 1 through 8, respectively. Thus, greatest variability in lanekeeping was generally exhibited during 2- and 4-line message reading, followed by reading a lo-digit phone number message.

Based on the main effects of CRT reading task message type, it appears that 2-line and 4-line messages can have substantial effects on visual allocation and lanekeeping performance. Steering and accelerator measures were sensitive to message type and so may be useful indicators of attentional demand away from the road scene ahead. Speed measures were not substantially affected by the CRT reading task, probably because of the relatively short durations of such visual tasks.

3.2 Driving Condition Effects During CRT Text Message Reading

In order to gain a better understanding of driver workload, analyses were conducted on the effects of driving condition factors (road type, lighting, traffic density) and two-factor interactions among them and with text message type.

Table 3.2.1 presents the effects of Road Type (undivided roadway, divided roadway) on all categories of workload measures collected during CRT Reading. Review of the table indicates a consistent pattern similar to that noted in Task 6 baseline. In terms of visual allocation, average device single glance durations are, on average, shorter, and average single road glance durations are longer on the undivided road type. Steering activity is greater on this roadway, as indicated by relatively greater steering position variance and fewer steering holds. Accelerator position variance is greater on the undivided highway, as are accelerator releases. Mean speed is lower and speed variance is higher on the undivided road type than on the divided road type. Finally, mean lane position is further from lane center on the divided road type. Similar effects were reported in Tijerina et al. (1995) for the 2-lane rural road, the same road type as indicated by the undivided roadway in this study. The greater path control demands and higher risk associated with opposite traffic suggest that this pattern of results reflects reasonable effects of road type on driving, even when executing CRT reading.

Table 3.2.2 presents the significant main effects of Light on workload measures collected during CRT reading. On average, the visual allocation measures indicate less visual attention allocated to the CRT and longer single glance durations to the road scene. Also, there is more time allocated to the CRT to complete a task, on average, at night when compared to daylight driving. This last effect is attributable to the greater number of glances to the CRT at night. There are also more steering reversals at night, slightly more accelerator holds at night, and tighter lanekeeping toward lane center at night than during the day. While these effects are usually small and of negligible practical significance, they all point in the direction toward more careful driving at night. It should be noted that there were no significant effects of ambient light level on travel speed measures.

Traffic Density (Table 3.2.3) had a significant main effect on mean lane position during CRT reading, $F(1, 409) = 4.57, p = 0.0332$. Under low traffic density, mean lane position averaged farther from lane center than under high traffic density (means of - 0.1 m and -0.02 m from lane center, respectively, with negative sign indicating right of lane center). Though of no practical significance, this difference is taken to indicate that drivers are sensitive to the presence of other vehicles and adjust their lanekeeping precision accordingly, even during CRT text message reading. However, the safety implications of driving a heavy vehicle substantially away from lane center keep the professional driver from straying too far from lane center.

Various two-factor interactions are presented in Table 3.2.4 through Table 3.2.8. These interactions are presented for completeness but will not be commented upon in detail in the interest of parsimony. Furthermore, these interactions generally appear to reflect relatively minor magnitude of effects relative to main effects such as CRT reading task or main effects of driving conditions like road type or lighting. Many of the interactions arose from slight variations, the causes of which are unclear.

Table 3.2.1 Significant Effects of Road Type (Undivided, Divided) on Workload Measures During CRT Text Message Reading

Dependent Measures	Road Type	
	Undivided	Divided
Device Average Glance Duration[a]	1.36 (0.45 1)*	1.68 (O.97)
Road Glance Average Duration[b]	0.85 (0.99)	0.63 (0.59)
Steering Position Variance[c]	43.87 (33.93)	31.45 (27.04)
Number of Steering Holds[d]	0.21 (0.54)	0.46 (0.86)
Accelerator Position Variance[e]	67.42 (163.28)	30.70 (87.33)
Number of Accelerator Releases[f]	0.141 (0.38)	0.05 (0.24)
Mean Speed[g]	20.80 (2.60)	23.40 (0.03)
Variance of Speed[h]	0.15 (1.17)	0.03 (0.09)
Lane Position[i], m	-0.16 (0.44)	0.05 (0.24)

Notes:

Corresponding F-values, and P-values are provided below.

a. F(2,409) =21.72, p = .0001
b. F(1,409) =7.22, p = .0075
c. F(l,409)=14.24,p = .0002
d. F(l,409) = 4.00, p = .0461
e. F(l,409) = 26.3, p = .0001
f. F(l,409) = 7.29,p = .0072
g. F(l,409)=127.76,p=.0001
h. F(l,409)=4.91,p=.0273
I. F(l,409) =50.05, p=.001

* Numbers in Parentheses are respective standard deviations associated with each mean value.

Table 3.2.2 Significant Effects of Light on Workload Measures During CRT Text Message Reading

Dependent Measures	Light Level	
	Night	Day
Number of Glances to Device[a]	2.97 (2.73)*	2.46 (2.25)
Average Duration Road Glances[b]	0.84 (0.98)	0.64 (0.60)
Total Glance Time to CRT[c]	4.24 (3.73)	3.38 (3.00)
Task Total Duration[d]	7.89 (7.06)	5.82 (4.87)
Number of Steering Reversals[e]	9.18 (8.78)	6.39 (5.75)
Number of Accelerator Holds[f]	2.28 (2.07)	1.96 (1.69)
Lane Position[g], m[b]	0.04 (0.26)	-0.15 (0.43)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1, 409) = 12.49$, $p = .0005$
b: $F(1, 409) = 4.50$, $p = .0345$
c. $F(1, 409) = 26.30$, $p = .000l$
d. $F(1, 409) = 23.65$, $p = .0001$
e. $F(1, 409) = 21.63$, $p = .0002$
f. $F(1, 409) = 4.18$, $p = .0414$
g. $F(1, 409) = 27.78$, $p = .0001$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 3.2.3 Significant Effects of Traffic Density on Workload Measures During CRT Text Message Reading

Dependent Measures	Traffic Condition	
	Low	**High**
Mean Lane Position"	-0.1 ***(0.39)***	***-0.02*** ***(0.36)***

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1, 409) = 4.57$, $p = .0332$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 3.2.4 Significant Interaction Between Traffic Density and Light on Workload Measures During CRT Text Message Reading

Dependent Measure	Light Level	Road Type	
		Undivided	Divided
Mean Lane Position[a]	Day	-0.37 (0.48)	0.051 (0.25)
	Night	0.03 (0.29)	0.053 (0.22)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1, 409) = 4.57$, $p = .0332$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 3.2.5 Significant Interaction Between Traffic Density and Light on Workload Measures During CRT Text Message Reading

Dependent Measures	Light Level	Traffic Density	
		Low	**High**
Accelerator Position Variance”			
	Night	34.95 (73.32)”	52.70 (130.72)
	Day	62.86 (192.64)	43.21 (102.27)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1, 409) = 4.00$, $p = .0461$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 3.2.6 Significant Interaction Between CRT Message Type and Road Type on Workload Measures During CRT Text Message Reading

Dependent Measures	CRT Message Type							
	1-Line Air Pressure Message	1-Line Time Message	2-Line Radio Message	4-Line Reading Message	1-Line Voice Dial Message	1-Line Auto-Dial Message	1-Line 7-Digit Dial Message	1-Line 10-Digit Dial Message
Number of Glances to CRT[a]								
Undivided Freeway	1.06 (0.24)	1.28 (0.52)	4.50 (1.67)	8.31 (2.70)	1.73 (1.18)	1.43 (0.68)	2.00 (0.90)	1.80 (0.80)
Divided Freeway	1.21 (0.66)	1.13 (0.34)	4.65 (2.22)	6.40 (2.44)	2.25 (1.40)	1.42 (0.57)	1.61 (0.90)	1.93 (0.99)
Total Glance Time to CRT[b]								
Undivided Freeway	1.54 (0.52)	1.52 (0.5)	5.78 (1.59)	11.20 (3.00)	2.30 (1.21)	1.77 (0.97)	2.52 (1.22)	2.36 (1.24)
Divided Freeway	1.84 (0.85)	1.65 (0.38)	7.05 (2.29)	10.13 (2.60)	2.56 (1.50)	2.44 (0.76)	2.40 (1.40)	2.86 (1.13)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(7, 409) = 2.11, p = .0411$
b. $F(7, 409) = 2.72, p = .0091$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 3.2.7 Significant Effects of Traffic Density and CRT Message Type on Accelerator Measures During Text Message Reading

Dependent Measures	Traffic Density	CRT Message Type							
		1-Line Air Pressure Message	1-Line Time Message	2-Line Radio Message	4-Line Reading Message	1-Line Voice Dial Message	1-Line Auto-Dial Message	1-Line 7-Digit Dial Message	1-Line 10-Digit Dial Message
Number of Accelerator Holds[a]	Low	1.55 (0.88)*	1.30 (0.57)	3.65 (2.36)	3.79 (2.76)	2.41 (1.32)	1.09 (0.68)	1.61 (1.29)	1.23 (0.44)
	High	1.72 (1.46)	1.33 (0.65)	2.80 (1.50)	4.63 (2.48)	1.73 (1.07)	1.58 (1.42)	1.72 (2.55)	1.47 (0.89)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(7, 409) = 2.41, p = .0198$

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* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 3.2.8 Significant Interaction of CRT Text Message Type and Light Level on Workload Measures During CRT Text Message Reading

Dependent Measures	Light Level	CRT Message Type							
		1-Line Air Pressure Message	1-Line Time Message	2-Line Radio Message	4-Line Reading Message	1-Line Voice Dial Message	1-Line Auto-Dial Message	1-Line 7-Digit Dial Message	1-Line 10-Digit Dial Message
Total Glance Time to CRT[a]	Day	1.52 (0.69)*	1.43 (0.45)	5.63 (1.44)	9.45 (2.61)	2.27 (1.40)	1.79 (0.71)	2.35 (1.38)	2.28 (1.18)
	Night	1.87 (0.71)	1.75 (0.39)	7.24 (2.29)	11.86 (2.56)	2.59 (1.36)	2.40 (1.02)	2.60 (1.17)	2.91 (1.18)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(7, 409) = 5.21, p = .0001$

* Numbers in parentheses are respective standard deviations associated with each mean value.

The effects of driving condition factors on workload measures may be summarized as follows. Road type (undivided vs. divided highway) can have a significant effect on several classes of driver workload measures. Ambient light level had fewer effects which were generally of no apparent practical significance. Traffic density in this study had a statistically significant effect on mean lane position but no practically significant effect; no other effects of traffic density were found. Various interactions were found but no consistent or compelling pattern was found. In total, the effects of driving conditions are secondary to task effects during CRT reading. Road type may be the only significant driving condition factor for future studies conducted under conditions similar to those used in this study.

3.3 Discussion

As indicated earlier, it appears that 2-line and 4-line messages can have substantial effects on visual allocation and lanekeeping performance. Steering and accelerator measures were sensitive to message type and so may be useful indicators of attentional demand away from the road scene ahead. Speed measures were not substantially affected by the CRT reading task, probably because of the relatively short durations of such visual tasks.

To reiterate, the effects of driving condition factors on workload measures may be summarized as follows. Road type (undivided vs. divided highway) can have a significant effect on several classes of driver workload measures. Ambient light level had fewer effects which were generally of no apparent practical significance. Traffic density in this study had a statistically significant effect on mean lane position but no practically significant effect; no other effects of traffic density were found. Various interactions were found but no consistent or compelling pattern was found. In total, the effects of driving conditions are secondary to task effects during CRT reading. Road type may be the only significant driving condition factor for future studies conducted under conditions similar to those used in this study.

There has been very little research examining text message display use in a highway setting. However, based on the data gathered using the procedures described in this report, it appears that 2-line or longer text message displays can be excessively taxing to the driver. The reading of these types of messages were associated with more glances away from the road scene and with shorter glances back to the road scene between these glance to the CRT. Similarly, 2-line and 4-line displays were associated with progressively more degraded driving quality as indexed by a variety of measures, including lane exceedences. Given that unplanned lane exceedences can lead to lane change, opposite direction, and roadway departure crashes, this is indicative of reduced safety margins or a marginal increase to crash hazard exposure.

While not a part of this study, the nature of the information content of even a l-line text message display may induce relatively excessive workload. For example, if abbreviations are used to maximize the use of a limited capacity l-line display, the driver who tries to read a message made up of abbreviations could have workload higher than any reported on here.

Abbreviations can be used to either facilitate data entry in computer systems or reduce message length for data display. In the former case, the operator must encode words, i.e., convert words into abbreviations. In the latter case, the operator must decode the abbreviations, i.e., convert them back into words. Ehrenriech (1985) pointed out in a review of abbreviations research that abbreviation rules that have been studied to date were oriented toward encoding and that optimal abbreviation rules to facilitate decoding are likely not the same. If no consistent rules are applied to abbreviations use, this could make even l-line text message very workload-intensive to the driver who attempts to understand the message itself.

4.0 **RESULTS: MANUAL TASKS**

4.1 Manual Task Effects

Table 4.1.1 presents the significant main effects of manual task (tuning the radio, auto-dialing, 7-digit dialing, and lo-digit dialing). As indicated in the table, Mean phone/radio glance duration was significantly different across manual tasks. It was slightly greater for the radio tuning task (M =1.20 s) than for the dialing tasks (means of 1.10, 0.97, and 1.01 s for 3-digit (auto-dial), 7-digit, and lo-dial dialing, respectively). The number of glances to the phone/radio was significantly different. The auto-dial task had the fewest number of glances, on average (mean of 4.86 glances), followed by radio tuning (M = 9.62 glances), 7-digit dialing (M = 10.24 glances), and lo-digit dialing (M = 10.57 glances). Total glance time to the device was also significant and followed the same trends as number of glances; that is, auto-dialing was associated with the lowest mean time the eyes were off the road. Also, the 7-digit and lo-digit dialing tasks, on average, took eyes off the road even longer than manually tuning the AM/FM radio, up to about 1 second longer for the lo-digit dialing task. Mean Road glance durations were not significantly different across the in-vehicle manual tasks (M = 0.92 s, overall). Taken together, these visual allocation results suggest that 7- and lo-digit manual dialing tasks match or exceed the visual demand of manual radio tuning in terms of number of glances, but mean glance duration is not as great.

The effects of manual task on steering, accelerator, and speed measures were also investigated. Significant differences were found for steering holds; the mean number of steering holds was greater during radio tuning and lo-digit dialing (means of 2.01 and 2.15 holds respectively) than for auto-dial and 7-digit dialing (means of 1.10 and 1.76 holds, respectively). Statistically significant differences were also found for number of steering reversals, with the smallest number of reversals being for the auto-dial task as opposed to radio tuning , 7-digit, or lo-digit dialing (means of 13, 22, 29.9, and 29.4 reversals, respectively). The lowest number of reversals for the simplest manual task may reflect the time course of task execution, i.e., there are fewer reversals because the time interval of in-cab task demand is shortest. Number of accelerator holds was statistically significant. On average, the auto-dial task had the fewest holds (M = 3 holds), lo-digit dialing had the most (M = 7.5 holds), while radio tuning and 7-digit dialing were in between these values (means of 5.4, 5.94 holds, respectively). Accelerator releases were not significantly different. Speed variance during manual task execution, on the other hand, was significantly different by manual task type. The variance was smallest for the auto-dialing task, greatest for the tune-radio and lo-digit dialing tasks. However, the magnitudes involved appear to be of no practical importance. Lane exceedence incidence was not significantly different across radio tuning, and auto-, 7-, and lo-digit dials (20, 16, 23, and 33 exceedences, respectively, across all drivers and all driving conditions). None of the other of the lanekeeping measures reported above was significant as a function of manual task.

Table 4.1.1 Significant Effects of Manual Task Type on Workload Measures Taken During Manual Task Execution

Dependent Measures	Manual Task Type			
	Tune Radio	Autodial (3-Digit)	7-Digit	IO-Digit
Device Average Glance Duration[a], s	1.10 (0.55)	1.20 (0.46)	0.97 (0.39)	1.01 (O-77)
Number of Glances to the Device[b], s	9.62 (1.74)	4.86 (2.93)	10.24 (5.10)	10.57 (4.15)
Total Glance Time to Device[c], s	1.26 (1.85)	1.42 (2.86)	3.57 (4.83)	4.29 (4.4)
Number of Steering Holds[d], count	2.01 (2.16)	1.10 (1.71)	1.76 (2.10)	2.15 (2.38)
Number of Steering Reversals[e], count	21.95 (15.54)	13.00 (14.35)	29.88 (35.06)	29.37 (17.47)
Number of Accelerator Holds[f], count	4.98 (3.69)	3.00 (3.12)	6.44 (8.57)	5.49 (4.01)
Variance of Speed[g], $(m/s)^2$	0.22 (0.52)	0.04 (0.06)	0.15 (0.25)	0.23 (0.44)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(3,190) = 6.55$, $p = 0.0112$
b. $F(3,190) = 31.49$, $p = 0.0001$
c. $F(3,190) = 28.64$, $p = 0.0001$
d. F-(3,190) = 6.35, $p = 0.0004$
e. $F(3,190) = 24.70$, $p = 0.0001$
f. $F(3,190) = 8.14$, $p = 0.0001$
g. $F(3,190) = 4.76$, $p = 0.0032$

* Numbers in parentheses are respective standard deviations associated with each mean value.

These data are taken as indications that manual activity can reliably affect steering behavior and accelerator inputs. Manual tasks like those indicated appear to have a small but negligible effect on speed variance as well. Note that the impact on lanekeeping was not significantly different as a function of manual task type. This last finding should not be interpreted as indicating that such manual tasks have no effect on lanekeeping, since lane exceedences did occur on 27 percent of trials during manual task execution. By comparison, lane exceedences occurred on only about 14 percent of trials while the drivers read the l-line "What's the current time?" CRT text message.

In summary, the effects of manual tasks associated with cellular phone dialing (and AM/FM radio tuning included as a baseline) were practically and statistically significant such that 7-digit and lo-digit dialing took more glances, on average, for completion than even radio tuning, with greater total time the eyes are off the road and on the device. Steering holds were found to be sensitive indicators of manual task execution, as were accelerator holds. There were no substantial effects of manual task execution on travel speed measures, probably because of the relatively short durations of such tasks. Lanekeeping measures were not significantly different among the different manual tasks but lane exceedences were found in 27 percent of all trials in which manual tasks were carried out. This suggests that cellular phone dialing can be disruptive to lanekeeping. As a point of reference, lane exceedences occurred on only about 14 percent of all trials during which a driver read the l-line quote "What is the current time?" message.

4.2 Driving Condition Effects During Manual Task Execution

Table 4.2.1 presents the significant main effects of Road Type (undivided, divided) on workload measures taken during manual task execution. In general, the effects of road type are consistent with those found for CRT reading. The greater driving demand of the undivided road type was associated, on average, with shortened device glance mean single glance durations, longer road glance durations, greater steering variability and fewer holds, greater accelerator variability and slightly greater accelerator holds, lower mean speed, greater speed variance, and greater mean lane position offset relative to lane center. Such effects can be interpreted by considering the greater path control demands associated with the undivided road type.

Table 4.2.2 presents the significant main effects of Light (night, day) conditions on workload measures collected during manual task execution. Clearly, the effects of light are substantially less than those of manual task or road type. At night, drivers averaged slightly slower travel speeds and maintained their lane position closer to lane center than during daytime driving. These effects are consistent with results reported in the Task 6 baseline study (Tijerina et al., 1995). However, the effects are small and appear to be of no practical significance.

Table 4.2.1 Significant Effects of Road Type on Workload Measures Taken During Manual Task Execution

Dependent Measures	Road Type	
	Undivided	Divided
Device Average Glance Duration[a], s	0.98 (0.23)*	1.07 (0.29)
Road Glance Average Duration[b], s	1.00 (0.50)	0.79 (0.33)
Steering Position Variance[c], degrees^2	57.65 (28.47)	41.96 (22.07)
Number of Steering Holds[d], count	1.35 (1.70)	2.19 (2.44)
Accelerator Position Variance[e], percent^2	77.04 (105.45)	39.54 (59.02)
Number of Accelerator Holds[f], count	5.50 (5.91)	4.39 (4.60)
Mean Speed[g], m/s	20.60 (2.61)	23.10 (1.27)
Variance of Speed[h], $(m/s)^2$	0.23 (0.50)	0.10 (0.17)
LANEPGSM[i], m	-0.17 (0.4)	0.02 (0.22)

Notes:

Corresponding F-values, and P-values are provided below.

a. $F(1,190) = 6.55$, $p = 0.0112$
b. $F(1,190) = 11.59$, $p = 0.0008$
c. $F(1,190) = 29.08$, $p = 0.0001$
d. $F(1,190) = 7.99$, $p = 0.0052$
e. $F(1,190) = 14.27$, $p = 0.0002$
f. $F(1,190) = 6.59$, $p = 0.0110$
g. $F(1,190) = 50.19$, $p = 0.0001$
h. $F(1,190) = 9.78$, $p = 0.0020$
I. $F(1,190) = 30.02$, $p = 0.0001$

* Numbers in Parentheses are respective standard deviations associated with each mean value.

Table 4.2.2 Significant Effects of Lighting Conditiou on Workload Measures Taken During Manual Task Execution

Dependent Measures	Lighting Condition	
	Night	Day
Mean Speed[a], m/s	21.50 (2.50)*	22.16 (2.30)*
LANEPOSM[b], m	0.04 (0.22)	-0.19 (0.40)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1,190) = 6.17$, $p = 0.0139$
b. $F(1,190) = 27.54$, $p = 0.0001$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 4.2.3 Significant Effects of Road Type and Lighting Condition Interaction on Workload Measures Taken During Manual Task

Dependent Measures	Light Level	Road Type	
		Undivided	Divided
Steering Position Variance[a], degrees^2	Night	62.08 (29.18)*	39.11 (0.50)
	Day	53.22 (27.27)	44.76 (26.64)
LANEPOSM[b], m	Night	0.06 (0.23)	0.02 (0.22)
	Day	-0.41 (0.42)	0.02 (0.22)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1,190) = 5.95, p = 0.0156$
b. $F(1,190) = 28.44$, $p = 0.0001$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 4.2.4 Significant Effects of Traffic Density and Road Type Interaction on Workload Measures Taken During Manual Task Execution

Dependent Measures	Road Type	Traffic Density Low	Traffic Density High
Steering Position Variance[a], degrees^2	Undivided	64.47 (36.71)*	55.11 (24.5)
	Divided	41.70 (25.05)	42.22 (18.90)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1,190) = 4.19, p = 0.0420$

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* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 4.2.5 Significant Effects of Traffic Density and Manual Task Interaction on Workload Measures Taken During Manual Task Execution

Dependent Measures	Traffic Density	Manual Task Type			
		Tune Radio	Autodial (3-Digit)	7-Digit	10-Digit
Number of Steering Holds[a], count	Low	2.12 (2.40)*	0.45 (0.67)	1.33 (1.78)	2.47 (1.77)
	High	1.90 (1.94)	1.50 (2.02)	1.97 (2.25)	2.02 (2.62)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(3,190) = 3.26, p = 0.0226$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 4.2.3, Table 4.2.4, and Table 4.2.5 present the significant interactions found during manual task execution. As indicated by Table 4.2.3, mean lane position is affected by both road type and lighting such that daytime driving on an undivided highway is associated with the greatest offset from lane center relative to driving on a divided highway or night driving on either type of roadway. Why this occurred is unknown but may generally reflect the impact of greater path control demand for the undivided road type and driver willingness to drive right of center when visual scanning for hazards is aided by day lighting. Similarly, steering position variance was greatest at night on the undivided roadway and least on the divided highway at night. Table 4.2.4 shows an effect related to steering variability that appears slight for the Traffic Density x Road Type interaction. Table 4.2.5 presents an interaction between Traffic Density and Manual Task on steering holds. While the number of steering holds differs substantially under low traffic density driving conditions, large differences among means are absent under high traffic density driving conditions. This is taken as evidence that the driving conditions are noted by drivers while attempting to complete the manual tasks, and that they adjust their behavior appropriately to maintain closed-loop control of the vehicle when warranted (i.e., with other vehicles present).

In summary, driving condition effects have influenced workload measures in ways that are generally in accord with intuition and past research. The effects of road type are greater than those for lighting, with interactions being less important. The impact of such driving condition effects is considered to be secondary to the manual task effects, both in terms of the number of dependent measures affected and the magnitude of the influence.

4.3 Discussion

The effects of manual tasks associated with cellular phone dialing (and AM/FM radio tuning included as a baseline) have previously been summarized. There were practically and statistically significant differences such that 7-digit and lo-digit dialing took more glances, on average, for completion than even radio tuning, with greater total time the eyes are off the road and on the device. Steering holds were found to be sensitive indicators of manual task execution, as were accelerator holds. There were no substantial effects of manual task execution on travel speed measures, probably because of the relatively short durations of such tasks. Lanekeeping measures were not significantly different among the different manual tasks but lane exceedences were found in 27 percent of all trials in which manual tasks were carried out. This suggests that cellular phone dialing can be disruptive to lanekeeping.

In this study, driving condition factors have influenced workload measures in ways that are generally in accord with intuition and past research. The effects of road type are greater than those for lighting and interactions are less important still. The impact of such driving condition effects is considered to be secondary to the manual task effects, both in terms of the number of dependent measures affected and the magnitude of the influence.

5.0 RESULTS: COGNITIVE TASK (Q&A DIALOGUE AND OPEN ROAD DRIVING)

For this analysis, no data were available for open road driving on an undivided roadway. However, for every combination of Cognitive Task (biographic dialogue, arithmetic dialogue, and open road driving) and Road Type (undivided, divided) observed, data were available on both levels of Light (day, night), and on both levels of Traffic Density (low, high). To maximize power in evaluating the statistical significance of Cognitive Task, Road Type, Light, Traffic Density, and two-way interactions of these fixed factors, all available data were used in the statistical testing. For each dependent measure, the ANOVA model applied included the fixed effects of Cognitive Task, Road Type, Light, Traffic Density, and two-way interactions of these factors. A random Subjects effect was also included in the repeated-measures ANOVA model. By use of the SAS™ General Linear Models (GLM) procedure with Type III Sums of Squares (SAS Institute, 1992), average levels of the remaining factors were controlled for when testing the statistical significance of a given factor. Thus, this approach allowed maximum use of the available data to provide justifiable significance test results. However, when presenting observed means and standard deviations to illustrate the effects found to be significant, care was taken to restrict the data appropriately to avoid confounding.

In presenting observed means and standard deviations to illustrate the effects of Light and Traffic Density, all data were included to compute cell means and standard deviations. This was justified because data were collected at both levels of Light and both levels of Traffic Density under every combination of Cognitive Task and Road Type observed.

For the significant effects of Cognitive Task and Road Type, on the other hand, descriptive statistics were based on data which were appropriately restricted. For instance, when an effect of Cognitive Task or any interactions that involved Cognitive Task were found to be significant, data for computation of cell means and cell standard deviations were restricted to those observations collected on divided highways, i.e., on the road type in which all three types of cognitive tasks were observed. This was done to avoid contaminating the effect of Cognitive Task by the effect of Road Type. Because open road driving was not observed on undivided roadways, including data on undivided highways would not accurately illustrate the effect which was found to be significant in the ANOVA model. A similar approach was used when presenting effects of Road Type. For responses which were significantly affected by Road Type and interactions that involved Road Type, data on open road driving were excluded when computing the cell means and standard deviations illustrating these effects. This approach was justified because there was never a statistically significant interaction between Cognitive Task and Road Type. Statistically significant effects are reported in subsequent sections.

5.1 Effects of Cognitive Task (Biographic Dialogue, Arithmetic Dialogue, and Open Road Driving) on Workload Measures during Cognitive Task Execution

Table 5.1.1 presents the statistically significant results of cognitive task on workload measures **taken** during cognitive task execution. Selected nonsignificant effects are also included in the table for comparison purposes. The three levels of cognitive task were biographic dialogue, arithmetic dialogue, and open road driving as a control condition. Note that each dialogue was a question-and-answer (Q&A) dialogue with pre-recorded questions to which the driver responded within a paced time frame. (See Table 2.4.2 for examples of the questions used).

As indicated in the table, cognitive task had a significant effect on several visual allocation measures. Average single glance duration to the road scene was significant, with arithmetic dialogue having the longest mean duration, followed by the biographic dialogue; open road driving had the shortest road glance duration, on average. This effect is not straightforward to interpret. If the driver is concentrating on the driving scene, this is good for driving safety. If the driver was concentrating on the dialogue and had essentially stopped scanning the road for potential hazards, this would have negative impact on driving safety, all else being equal. Unfortunately, the video method used to capture visual allocation data was not sufficiently precise to capture small saccadic eye movements or vergence eye movements that might indicate any “tunnel vision” effects of workload. However, some evidence that the drivers, on average, reduced their scanning while engaged in cellular phone dialogues comes from the significant effect of cognitive task on fraction of time spent scanning the mirrors. Open road driving was associated with a mean of 0.124 or approximately 12.4 percent of the time spent sampling the mirrors. Biographic and arithmetic dialogues were associated with mean fractions of 0.066 and 0.057, respectively. Thus, inclusion of either dialogue reduced mirror sampling from a little over 12 percent to about 6 percent. Number of mirror glances also differed significantly ($p < .000l$), with Arithmetic and Biographical dialogue having less mirror glances than open road driving (means of 2.73, 3.17, and 7.30 glances per minute, respectively). This suggests that even a non-visual task like voice communications can affect visual allocation and reduce the heavy vehicle driver’s situation awareness provided by mirror sampling.

The cognitive task effects on steering measures over one minute were assessed as well. The mean number of steering holds was not significantly different among different tasks. Mean number of steering reversals was significant ($p < .000l$) and was greatest for the arithmetic dialogue and about equal for the biographical dialogue and open road driving. From a workload perspective, steering holds should increase as attentional demand away from the road scene increases since there is competition between closed-loop driving and in-cab task execution (Tijerina et al., 1995). Conversely, steering reversals might decrease with increased attentional demand or increase as a result of the lane tracking error that must be corrected during steering holds. No clear pattern emerges from these data. This pattern of results has

Table 5.1.1 Significant Effects of Cognitive Task Type on Workload Measures Taken During Cognitive Task Execution

Dependent Measures	Cognitive Task		
	Biographic Dialogue	Arithmetic Dialogue	Open Road Driving
Road Glance Average Duratio[a], s	5.64 (7.47)*	7.81 (9.89)	3.06 (2.63)
Fraction of Time Spent Sampling Mirrors[b], proportion	0.066 (0.047)	0.057 (0.039)	0.124 (0.057)
Number of Mirror Glances per Minute[c], count	3.17 (2.82)	2.73 (2.79)	7.30 (3.36)
Number of Steering Reversals[d], count	106.58 (20.46)	149.41 (27.84)	119.25 (22.45)
Number of Steering Holds[e], count	6.06 (4.77)	10.59 (7.30)	11.75 (6.94)
Steering Position Variance[f], degrees^2	49.75 (29.87)	85.89 (46.24)	57.23 (63.46)
Number of Accelerator Holds[g], count	23.58 (9.39)	28.18 (14.52)	23.81 (10.65)
Number of Accelerator Releases[h], count	0.42 (0.88)	0.74 (1.40)	0.38 (1.09)
Mean Speed[i], m/s	23.70 (1.00)	22.98 (1.96)	23.53 (0.85)
Variance of Speed[j], $(m/s)^2$	0.42 (0.38)	3.84 (17.42)	0.70 (1.46)
Number of Lane Exceedences[k], count	0.29 (0.53)	0.78 (1.48)	1.06 (1.34)

Table 5.1.1 (Continued)

Dependent Measures	Cognitive Task		
	Biographic Dialogue	**Arithmetic Diiogue**	**Open Road Driving**
Lane Position Variance[l], m^2	0.03 (0.03)	0.03 (0.03)	0.04 (0.02)
LANEPOSM[m], m	0.03 (0.18)	0.07 (0.19)	0.10 (0.13)

Notes:

Corresponding F-values, and P-values are provided below.

a. $F(2,96) = 6.83, p = .00017$
b. $F(2, \%) = 28.40, p = .0001$
c. $F(2, 96) = 11.92, p = .0001$
d. $F(2,96) = 17.87, p = .0001$
e. Not statistically significant.
f. Not statistically significant.
g. $F(2, 96) = 4.15, p = .0186$
h: Not statistically significant.
i. Not statistically significant.
j. Not statistically significant.
k. Not statistically significant.
1. Not statistically significant.
m. Not statistically significant.

* Numbers in Parentheses are respective standard deviations associated with each mean value.

no clear interpretation and may well reflect the fact that many factors other than workload can affect such measures.

Accelerator holds were significantly different as a function of cognitive task. Holds, indicative of increased attentional demand away from the driving task, were somewhat more frequent for the arithmetic dialogue than either biographic dialogue or open road driving. Finally, for the cognitive task, there were no significant differences in mean speed or speed variance or lane position variance across the biographical, arithmetic, and open road driving (control) conditions. Lane exceedences per one minute of driving were also not statistically significantly different as a function of cognitive task.

Based on the data analysis reported here, it appears that dialogues such as those used in this study can significantly affect mirror sampling when compared to open road driving without any cellular phone dialogue. This is taken as evidence that driver situation awareness is decreased during cellular phone dialogues relative to open road driving. The pattern of steering reversals was not interpretable. Accelerator holds, indicative of increased attentional demand away from the road scene, were slightly more frequent with arithmetic dialogue and may have some use as an indicator of driver attentional state. However, no degradation of driving performance in terms of speed maintenance and lanekeeping measures was noted. This is taken as evidence that the drivers in this study did not degrade in terms of speed maintenance and lanekeeping performance while engaged in cellular phone dialogue. Rather, the competition with the driving task manifested itself in reduced scanning to the mirrors, an indication of reduced situation awareness.

5.2 Effects of Driving Conditions during Cognitive Task Execution

Table 5.2.1 presents significant effects of Road Type on workload measures during cognitive task execution. The effects of undivided roadway versus divided roadway types generally reflects those reported in other sections of this report. On average, the undivided roadway, with its greater driving demands, was associated with less mirror sampling, longer road glance durations, greater steering position variability, greater accelerator variability, slower travel speeds, greater speed variability, and slightly greater deviation from lane center in terms of lane position. The greater mean incidence of accelerator releases per one minute of driving may reflect the greater demands for speed control on the undivided roadway. In general, these effects are like those reported in the Task 6 baseline study from this program of research.

Table 5.2.2 presents significant effects of Light on workload measures during cognitive task execution. As indicated in the table, the effects of ambient lighting were substantially fewer in number and lesser in magnitude, though they are in the direction expected from past research and intuition. The professional drivers tended to spend slightly less time sampling the

Table 5.2.1 Significant Effects of Road Type on Workload Measures Taken During Cognitive Task Execution

Dependent Measures	Road Type	
	Undivided	Divided
Fraction of Time Spent Sampling Mirrors[a], proportion	0.022 (0.026)	0.061 (0.044)
Road Glance Average Duration[b], s	12.41 (15.92)	6.65 (8.67)
Steering Position Variance[c], degrees^2	133.79 (145.87)	66.58 (42.14)
Number of Accelerator Releases[d], count	1.84 (2.43)	0.57 (1.16)
Accelerator Position Variance[e], percent^2	306.06 (221.60)	152.10 (157.65)
Mean Speed[f], m/s	20.53 (3.24)	23.37 (1.55)
Variance of Speed[g],	3.30 (6.21)	2.01 (11.90)
LANEPOSM[h], m	-0.10 (0.41)	0.05 (0.18)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1,96) = 31.26, p = 0.0001$
b. $F(1,96) = 24.58, p = 0.0001$
c. $F(1,96) = 41.88, p = 0.0001$
d. $F(1,96 = 8.70, p = 0.0040$
e. $F(1,96) = 14.53, p = 0.0002$
f. $F(1,96) = 17.18, p = 0.0001$
g. $F(1,96) = 12.87, p = 0.0005$
h: $F(1,96) = 14.94, p = 0.0002$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 5.2.2 Significant Effects of Lighting Condition on Workload Measures Taken During Cognitive Task Execution

Dependent Measures	Light Level	
	Night	Day
Fraction of Time Spent Sampling Mirrors[a], proportion	0.042 (0.041)	0.065 (0.060)
Accelerator Position Variance[b], percent'	200.06 (10.78)	204.04 (10.50)
LANEPOSM[c], m	0.078 (0.21)	-0.11 (0.37)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(l,96) = 4.20$, $p = 0.0431$
b. $F(1,96) = 5.33$, $p = 0.0231$
c. $F(1,96) = 4.31$, $p = 0.0406$

* Numbers in parentheses are respective standard deviations associated with each mean value.

mirror at night, no doubt reflecting the lower traffic density that tends to arise with night driving. The drivers tend to maintain tighter lanekeeping at night, as evidenced by slightly smaller mean lane position offset from lane center. While the difference in means is probably of no practical significance, this may reflect slightly greater concern for proper tracking of the vehicle when it is dark. No comment will be made about the accelerator position variance differences because they are trivial, albeit statistically reliable.

Table 5.2.3 presents significant effects of the interaction between Road Type and Light on workload measures taken during cognitive task execution. The mean lane position effect may reflect an interplay between driver concerns for proper vehicle tracking when driving at night and the greater path control demands of the undivided roadway. Under daylight conditions, in particular, it appears that the driver, on average, is more willing to drive offset from lane center to a degree, perhaps to ease steering demands and capitalize on the relatively greater visibility. The speed variance effects are not readily interpretable. However, it is clear that night driving on a divided highway was associated with the least speed variability. Taken together, these effects, though in the right direction, appear to reflect minor variations in driving.

Table 5.2.4 presents significant effects of the interaction between Light and Traffic Density on workload measures taken during cognitive task execution. Steering holds tended to be more frequent in daylight driving and were even more prevalent in low traffic density. Steering position variability was greater under high traffic density than under low traffic density in daylight driving, but this difference was even more pronounced when driving at night. This may reflect the greater lanekeeping precision required by the presence of other vehicles as well as the greater lanekeeping precision exhibited by the drivers when driving at night. The accelerator position variance was significantly different as a function of ambient lighting condition only for high traffic density; more variability was associated with daylight driving, though why this effect arose is not known. These interaction effects appear to be of no practical significance.

Table 5.2.5 presents significant effects of the interaction between Cognitive Task Type and Traffic Density on workload measures taken during cognitive task execution. No apparent consistent pattern emerges from these results. Given that many factors affect steering and accelerator inputs besides in-cab device demand, this is perhaps not surprising.

The effects of driving condition demands on workload measures collected during cognitive task execution can be summarized as follows. Road type effects were most pronounced, followed by ambient lighting effects. Some interactions were also found thought the number of dependent measures and the magnitude of effects suggests that these are of relatively little importance. Compared to task effects, the impact of driving conditions on workload measures can vary from substantial (in the case of road type effects) to negligible. Future workload assessments should probably include road type differences or at least report the road types being used. Light effects may be ignored. Traffic density, though expected to

Table 5.2.3 Significant Effects of Road Type and Lighting Condition Interaction on Workload Measures Taken During Cognitive Task Execution

Dependent Measures	Light Level	Road Type Undivided	Road Type Divided
Variance of Speed[a], $(m/s)^2$	Night	3.86 (7.49)*	0.32 (0.30)
	Day	2.59 (4.04)	3.82 (17.09)
LANEPOSM[b], m	Night	0.11 (0.24)	0.03 (0.18)
	Day	-0.36 (0.44)	0.07 (0.18)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1,96) = 4.72, p = 0.0324$
b. $F(1,96) = 15.55, p = 0.0002$

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* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 5.2.4 Significant Effects of Lighting Condition and Traffic Density Interaction on Workload Measures Taken During Cognitive Task Execution

Dependent Measures	Traffic Density	Light Level	
		Night	Day
Number of Steering Holds”, count	LOW	6.64 (2)*	9.26 (6.70)
	High	6.90 (5.13)	8.02 (6.69)
Steering Position Variance[b], degrees^2	Low	61.60 (77.40)	88.78 (134.56)
	High	106.94 (113.02)	93.68 (95.23)
Accelerator Position Variance[c], percent2	Low	173.99 (129.93)	173.12 (164.29)
	High	213.32 (218.36)	258.32 (216.58)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(1,96) = 5.01, p = 0.0276$
b. $F(1,96) = 4.54, p = 0.0358$
C. $F(1,96) = 4.79, p = 0.0311$

* Numbers in parentheses are respective standard deviations associated with each mean value.

Table 5.25 Significant Effects of Cognitive Task Type and Traffic Density Interaction on Workload Measures Taken During Cognitive Task Execution

Dependent Measures	Traffic Density	Cognitive Task Type: Biographic Dialogue	Cognitive Task Type: Arithmetic Diiogue	Cognitive Task Type: Open Road Driving
Steering Position Variance[a], degrees'	Low	42.82 (22.40)*	111.41 (69.10)	33.59 (18.50)
	High	54.12 (33.59)	81.46 (41.68)	109.23 (96.58)
Number of Accelerator Holds[b], count	Low	24.67 (4.83)	37.75 (13.50)	21.18 (8.82)
	High	22.89 (11.46)	26.52 (14.31)	29.60 (13.05)
Accelerator Position Variance[c], percent^2	Low	216.76 (145.46)	118.86 (159.20)	90.78 (95.15)
	High	166.23 (181.61)	112.46 (138.12)	255.49 (212.52)

Notes:

Corresponding F-values, and p-values are provided below.

a. $F(2,96) = 3.79, p = 0.0261$
b. $F(2,96) = 4.58, p = 0.0126$
c. $F(2,96) = 4.78, p = 0.0105$

* Numbers in parentheses are respective standard deviations associated with each mean value.

have a significant impact on workload, did not in this study. However, the traffic density observed in this study may be slight compared to other areas of the country with greater volumes of traffic.

5.3 Discussion

As indicated earlier, it appears that dialogues such as those used in this study can significantly decrease mirror sampling behavior as compared to open road driving. This is taken as evidence that driver situation awareness is decreased during cellular phone dialogues relative to open road driving. The pattern of steering reversals was not interpretable and steering holds were not significantly different as a function of cognitive task level. Accelerator holds, indicative of increased attentional demand away from the road scene, were slightly more frequent with arithmetic dialogue and so may have some use as an indicator of driver attentional state. However, no degradation of driving performance in terms of either speed maintenance or lanekeeping measures was noted. This is taken as evidence that the drivers in this study did not degrade in terms of speed maintenance and lanekeeping performance while engaged in cellular phone dialogue. Rather, the competition with the driving task manifested itself in reduced scanning-to the mirrors, an indication of reduced situation awareness.

The effects of driving condition demands on workload measures collected during cognitive task execution varied from substantial to trivial. Road type effects had some substantial impacts on workload measures. On the other hand, light effects and various interactions among driving condition factors were generally small and can probably be ignored. Interestingly, traffic density did not have a substantial main effect on any workload measures, perhaps because even “high” traffic density for this study was relatively low.

6.0 GENERAL DISCUSSION

This study assessed the driver workload imposed by a text messaging system and cellular phone on heavy vehicle drivers under various driving conditions. Sixteen (16) professional commercial vehicle operation (CVO) licensed drivers drove an instrumented heavy truck over a 4-hour period on public roads under various conditions of ambient lighting (day or night), traffic density (light or heavy), and road type (divided or undivided). Within driving condition combinations, various levels of text message reading, cellular phone dialing, radio tuning, and communications dialogue were completed by the driver. Continuous measures were taken of visual allocation, steering and accelerator activity, speed maintenance and lanekeeping performance.

A prototype text message display system and cellular phone system were chosen for evaluation based on work from Task 3 of this research program that indicated such systems would provide a range of workload assessment challenges. Furthermore, the in-cab task taxonomy developed in Task 4 also indicated that these two technologies would involve a range of tasks with which to determine the sensitivity of candidate workload measures. These two technologies also serve as surrogates for a broader range of technologies with similar attributes or driver demand characteristics. Thus, results from this study can be used to gauge the workload impact of systems with similar attributes. Note that text message display use would be a Visual Only task; manual dialing of the cellular phone would be a Visual-Manual task; dialogue carried out over the cellular phone would largely constitute a Cognitive Only task.

Results have been presented for the three main components of the study:

- Reading text messages of various lengths and with various content from a prototype CRT Text Message display;
- Manually dialing a cellular phone in any of three dialing configurations (auto-dial, 7-digit dial, or lo-digit dial), along with manually tuning a radio as a baseline; and
- Engaging in question-and-answer dialogue with either biographic questions or arithmetic questions on a cellular phone, along with manual radio tuning as a baseline.

The reader is referred to the appropriate sections of this report for details of each analysis. In this final section, general comments will be provided.

This study was intended to demonstrate the sensitivity of candidate workload measures to assess workload variation with two in-cab devices. In terms of establishing the sensitivity of the workload measurement system to variations in heavy vehicle driver workload, this study met this goal. However, the original intent of the task was to establish the conditions under which it would be safe to use or operate the technologies tested. Here, the study is equivocal. This is because the state of the art in driver workload assessment is such that relative assessments are feasible but absolute assessments that predict crash occurrence are not feasible. For a detailed discussion of the difficulties associated with predictive safety impact assessments, see Tijerina, Wierwille, Kiger, and Rockwell (1995).

The text message display analysis indicated that 2-line and 4-line messages like those used in this study can have substantial effects on visual allocation (increased time looking away from the road scene, shortened glances to the road scene during message reading) and lanekeeping performance (e.g., greater incidence of unplanned lane exceedences). Thus, a recommendation is offered that text messaging systems be kept to a l-line display of perhaps 55 characters, with the display parameters of character size, luminance, polarity, and contrast set to levels established by ergonomics research. It was also mentioned that, though not pursued in this study, there is evidence that increased workload and comprehension demands may be associated with attempts to put too much information into even the l-line display format. This is an area in need of further research. However, the review provided by Ehrenreich (1985) strongly suggests that abbreviations for data display (as opposed to data entry) will be fraught with problems. Such problems may be aggravated by the demands of concurrent driving.

The analysis of manual activity focussed for this study on various levels of manual dialing of a cellular phone. Manual radio tuning was included as a baseline condition based on previous research. Results indicated substantial differences in visual demand associated with 7-digit and lo-digit dialing. There were no substantial effects of manual task on speed maintenance or lanekeeping performance. However, lane exceedences were observed on 27 percent of all trials. Given that the drivers were probably very vigilant since they knew they were participating in a study, this is disturbing. As a point of reference, only about 14 percent of the observations for reading a l-line "What is the current time?" CRT text message involved lane exceedences. Furthermore, the manual radio tuning task was chosen as a baseline because it represents a societally accepted, though high-demand task. However, manual radio tuning is itself associated with crashes (Wierwille and Tijerina, in press). Thus, even with professional truck drivers, it is advisable to streamline the manual dialing aspects of the cellular phone, either with auto-dial features that minimize the number of keystrokes required or perhaps a voice-dial feature that does not require manual input or eyes off the road at all.

Heavy vehicle drivers tend to spend a great deal of time engaging in dialogues on CB radios. This has the benefit of keeping the drivers alert while driving. However, the present study showed that even relatively simple question-and-answer dialogues can have subtle effects on safety-relevant driving behaviors. In particular, the results indicated that visual scanning, as measured by mirror sampling, was cut by almost 50 percent on average when the driver was engaged in dialogue as compared to engaged in open road driving without dialogue. This is a potential cause for concern in that it represents a marginal increase in crash hazard exposure. From this, one may hypothesize that such in-vehicle device workload does not degrade the highly over-learned skills of driver-vehicle speed and lanekeeping performance among professional truck drivers. Instead, in-cab device workload decreases driver monitoring for hazards on the roadway.

It is interesting to consider also subjective assessments made by the drivers during the data collection debrief. When subjects were debriefed after the run (See Appendix E for the questions and responses), they reported some difficulty in phone use but over half reported no difficulty in executing the tasks.

When asked to rate workload imposed by the four road sections, i.e., divided (I-270) roadway-day, divided roadway-night, undivided roadway (SR- 16 1)-day and undivided roadway-night, the subjects rated SR-161 to have a higher workload than I-270 and night operation with a higher workload than daytime operation. Thus, SR-161 night workload averaged 39.7 on a scale of 100 vs. 12.3 for I-270 day. The absolute value of these scores are less important than the relative scores. When asked to rate the in-cab tasks in terms of workload, the drivers gave average workload ratings ranging from 19.5 for the 3-digit dialing task to 27.3 for the lo-digit dialing task with CRT reading and cognitive load falling between these two values.

When asked to rate workload (again on a 100 point scale) for the highest workload road condition (SR-161 night) and the highest task workload (lo-digit dialing), the subjects gave a mean response of 56.9 suggesting an additive effect. Most of the drivers believed the in-cab tasks were realistic although many expressed some concern about phone usage. This latter response is understandable since few had cellular phone experience and none had used them in regular truck driving. Thus, drivers in this study apparently were aware of the potential hazards associated with the technologies to which they were exposed.

REFERENCES

Alm, H., & Nilsson, L. (1990, October). ***Changes in driver behaviour as a function of hands free mobile telephones: A simulator study.*** Linkoping, Sweden: Swedish Road and Traffic Research Institute.

Boase, M., Hannigan, S., & Porter, J. M. (1988). Sorry, can't talk now... just overtaking a lorry: The definition and experimentation investigation of the problem of driving and handsfree carphone use. In E. D. Megaw ***(Ed.), Contemporary ergonomics, 1988*** (pp. 527 - 532). London: Taylor and Francis.

Boff, K., Kaufman, L., & Thomas, J. P. (Eds.)(1986). ***Handbook ofperception and performance - Volume I: Sensory processes and perception. New*** York: Wiley and Sons.

Brookhuis, K. A., De Vries, G., & De Waard, D. (1991). The effects of mobile telephoning on driving performance. ***Accident Analysis and Prevention, 23(4), 306-3*** 16.

Brown, I. D., Tickner, A. H., & Simmonds, D. C. V. (1969). Interference between concurrent tasks of driving and telephoning. ***Journal of Applied Psychology, 53(5),*** 419 - 424.

Chovan, J. D., Tijerina, L., Alexander, G. & Hendricks, D. L. (1994, March). ***Examination of lane change crashes and potential IVHS*** countermeasures (Report No. DOT HS 808 071 and DOT-VNTSC-NHTSA-93-2). Cambridge, MA: John A. Volpe National Transportation Systems Center.

Drory, A. (1985). Effects of rest and secondary task on simulated truck driving task performance. ***Human Factors, 2 7(2), 20*** l-207.

Ehrenreich, S. L. (1985). Computer abbreviations: Evidence and synthesis. ***Human Factors,*** 27(2), 143-155.

Hendricks, D., Allen, J., Tijerina, L., Everson, J., Knipling, R., Wilson, C. (July, 1992). ***VNTSC ZVHS program Topical Report #2: Single vehicle roadway*** departures (Volumes I and II) (Contract No. DTRS-57-89-D-00086). Columbus, OH: Battelle.

Kiger, S. M. , Rockwell, T. H., Niswonger, S., Tijerina, L., Myers, L. B., & Nygren, T. (1992, September). ***NHTSA heavy vehicle driver workload assessment Task 3 interim report: Task analysis data collection*** (Contract No. DTHN22-91-C-07003). Columbus, OH: Battelle.

Liebowitz, H. W. (1988). The human senses in flight. In E.L. Wiener and D.C. Nagel ***(Eds.), Human factors in aviation*** (pp. 83-l 10). San Diego, CA: Academic Press.

Liebowitz, H. W., & Owens, D. A. (1986). We drive by night. Psychology ***Today,*** 20(l), ***54 - 58.***

MacDonald, W. A., & Hoffman, E. R. (1980). Review of relationships between steering wheel reversal rate and driving task demand. ***Human Factors, 22(6), 733-739.***

McKnight, A. J., & McKnight, A. S. (1991, January). The ***effect of cellular-phone use upon driver attention,*** Washington, DC: National Public Services Research Institute.

Mironer, M., & Hendricks, D. L. (1994, August). ***Examination of single vehicle roadway departure crashes and potential IVHS countermeasures (Report No.*** DOT HS 808 144 and DOT-VNTSC-NHTSA-94-3). Cambridge, MA: U.S. Department of Transportation John A. Volpe National Transportation Systems Center.

Pachiaudi, G., & Chapon, A. (1994, May). ***Car phone and road safety*** (Paper No. 94 S2 0 09). Paper presented at the XIVth International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany.

Parkes, A. M. (1993). Voice communications in vehicles. In S. Franzen and A. M. Parkes ***(Eds.), Driving future vehicles*** (pp. 219 - 228). London: Taylor and Francis.

Serafin, C., Wen, C., Paelke, G., & Green, P. (1993). Car phone usability: A human factors laboratory test. ***Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting -- 1993, 220 - 224.***

Stein, A. C., Paresghian, Z., & Allen, R. W. (1987, March). ***A simulator study of the safety implications of cellular mobile phone*** use (Paper No. 405). Hawthorne, CA: Systems Technology Inc.

Tijerina, L., Kiger, S. M., Rockwell, T. H., & Wierwille, W. W. (1995, June). ***NHTSA heavy vehicle driver workload assessment Task 5 interim report: Workload measurement protocol development draft driver workload assessment protocol*** (Contract No. DTHN22-91-C-07003). Columbus, OH: Battelle.

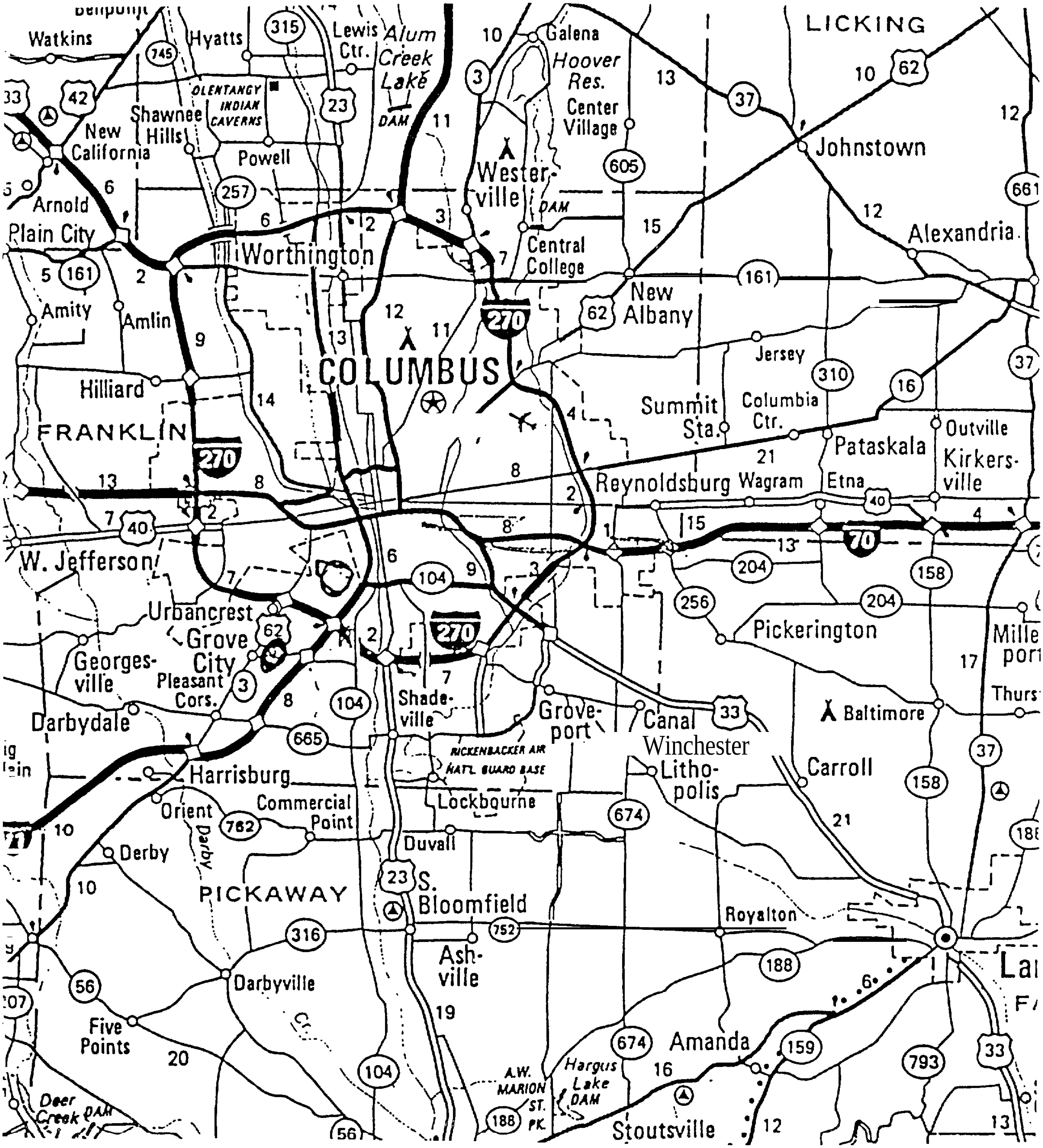
Tijerina, L., Kiger, S. M., Rockwell, T. H., Tornow, C. E., Kinateder, J. G., & Kokkotos, F. (1995, September). ***NHTSA heavy vehicle driver workload assessment Task 6 interim report: Workload measurement protocol development baseline data study*** (Contract No. DTHN22-91-C-07003). Columbus, OH: Battelle.

Wierwille, W. W. (1994). ***Overview of research on driver drowsiness definition and driver drowsiness detection*** (Paper No. 94 S3 0 07). Paper presented at the XIVth International Technical Conference on the Enhanced Safety of Vehicles, Munich, Germany, May 23-26, 1994.

Zwahlen, J., Adams, H. T., Jr., & Schwartz, J. J. (1988). ***Safety aspects of cellular telephones in automobiles*** (Paper No. 88058). ISATA Conference, Florence, Italy.

Appendix A: Map of Test Route

APPENDIX A - MAP OF TEST ROUTE



Appendix B: Subject Consent Form - Task 7

APPENDIX B
SUBJECT CONSENT FORM - Task 7

Title of Study: Heavy Vehicle Driver Workload Assessment Project

Study Description Many high technology in-cab devices are beiig proposed for use in heavy trucks (e.g., route guidance systems, trip recorders, text displays, communications systems, etc.). These devices sometimes introduce additional tasks which might compete with the driver's primary job of safely controlling the vehicle at all times. Battelle is conducting a research project for the National Highway Traffic Safety Administration (NHTSA) to measure the effects on drivers of introducing high technology in-cab devices. We believe that this work will contribute significantly toward enhancing safety and promoting a driver-c-entered approach to the development of high technology in-cab devices.

As part of our work, Battelle (through our subcontractor R&R Research, Inc.) must collect data from drivers under various normal driving conditions. The purpose of this data collection is to better understand the various driving tasks drivers must perform today, the driving conditions under which they work, and the driver behaviors, performance, and attitudes which may reflect driver workload.

As a voluntary participant, you will drive a US Government tractor-semitrailer through public roadways selected for the study. During testing, a ride-along observer will be in the vehicle with you on your assigned route. This observer will operate measurement equipment, give instructions to you about where to drive, and ask you to operate equipment commonly found in modem heavy vehicles. On-the-road data collection will include observation of driving behaviors and tasks performed, video taping of the road scene and the driver's visual scanning patterns, and various measures of driving performance such as lane keeping, speed control, headway maintenance, and so forth. The ride-along observer will ask you to visually scan the west coast mirrors and selected gauges on the instrument panel or to manipulate knobs or switches when driving permits. As a part of the study you will also be asked to read text messages presented on a display in the cab and to make calls using a cellular telephone. The ride-along observer will ask you to answer questions about heavy vehicle driving.

You. the driver, are in control and will be the final judge on whether or when to respond to any request. Do not blindly follow any request. Follow our requests and answer our questions only when it is safe and convenient to do so,

Risks: While driving for this study, you will be subject to all risks normally present during heavy truck driving. There are no known physical or psychological risks associated with participation in this study beyond those normally found in heavy truck driving. However, you must be aware that accidents can happen any time while driving.

You remain legally liable for your actions during this testing. You will not intentionally be asked to drive illegally. Should an action requested of you by the ride-along observer seem illegal, you are not to do it. Should yo receive a speeding ticket or some other legal penalty for your driving during this testing, you understand that neither Battelle, R&R Research, Inc., nor the US Government will compensate you for any fines or otherwise assist you in resolving legal problems arising out of any illegal action.

Benefits: The results of this study will provide valuable guidance for the development of an evaluation method to determine the safety of high technology in-cab devices offered for use in heavy trucks.

By participating in this study, you will get some exposure to transportation research methods and will be lending your expertise and experience to support highway safety research regarding future use of in-cab devices.

Confidentiality: We are gathering information on heavy vehicle driving. We are **not testing** you. If you agree to participate in this study, you name will not be released to anyone other than the principal investigator. Individual performance will not have the subject's name associated with it in any interim or final reports. This confidentiality will be maintained.

Principal Investigator: If you have any questions or comments in relation to this study, please contact the following person:

Louis Tijerina, Ph.D.
Battelle
505 King Avenue
Columbus, OH 43201
Phone: 614-424-5406

Right to withdraw: YOU HAVE THE OPTION OF WITHDRAWING AT ANY TIME DURING THE COURSE OF THE STUDY WITHOUT PENALTY.

Compensation: You will be paid a sum of $100.00 to participate in this study for approximately four hours of your time. You are entitled to this pay even if you elect to withdraw at any time during the course of the study.

Caution: As mentioned earlier, there are no known risks associated with participation in this study beyond those normally found in heavy truck driving. You will be the final judge of when or whether to respond to a question or request by the ride-along observer. If new information becomes available which might reasonably be expected to affect your willingness to continue to participate in the study, you will be so informed.

Approximately sixteen (16) drivers are expected to participate in this study.

It is not anticipated that you will be informed of the results of this study.

Disposition of Informed Consent: The Principal Investigator will retain a copy of this Informed Consent Form. A copy of this form will also be provided to you upon completion of participation in this study.

INFORMED CONSENT:

I, ________________________, UNDERSTAND THE TERMS OF THIS AGREEMENT
(Print your name)
AND CONSENT TO PARTICIPATE IN THIS STUDY.

Signature ______________________________ Date: ____________________

Address: ______________________________________

____

Telephone No. ____________________________

Appendix C: Subject Instructions - Task 7

APPENDIX C - SUBJECT INSTRUCTIONS - Task 7

"Thank you for agreeing to help us in this study. The major objective of the study is to better understand the various driving tasks truck drivers must perform and the effects of different highway, traffic and weather conditions on driving. One of the key questions of the study is identifying where drivers look while performing their tasks.

"To record data for the project, we have mounted several video cameras in the cab. One video camera is mounted on the dash and is focused on your face to record your glances. Other cameras are positioned to record where you reach and to record the road, traffic and the weather conditions on the trip.

"On our run today we will be going [insert general description of route used]. As the trip progresses, I will remind you of upcoming route changes far enough in advance for you to make preparations for changing lanes or making a turn.

During the run we will observe you as you naturally drive. We will also ask you to perform extra driving tasks. Some are related to text messaging, i.e., instructions given to you on a CRT screen rather than verbally. For example, read air pressure.

We will also ask you to use the cellular phone with instructions again coming from the CRT display.

These tasks are intended to represent what some truck drivers might be using today, i.e., text messages from the dispatcher and use of a cellular phone.

"It is essential for you to understand that safe ***driving comes*** *first.* Drive the truck first and perform the other tasks only <u>when</u> it is safe and convenient for you to do so. Never blindly follow our instructions if you feel the safety of the trip would be jeopardized. That means that you may tell us that you can't perform these extra driving tasks and still maintain safe operation of the truck. Always obey the rules of the road.

"You may stop the study at any time during the trip should you wish to do so.

"As a token of our appreciation for your assistance, you will be paid $100.00 for participating in and completing the study. We also want to assure you that your name will remain anonymous – only our immediate project staff will know who you are.

"Do you have any questions?"

Appendix D: Criteria for High vs. Low Traffic

APPENDIX D - CRITERIA FOR HIGH VS. LOW TRAFFIC

A) 2-Lane, Undivided Highway

	Mean Number of Vehicles in Field of View During Trial: 1	>1
No Car Following	Low	High
Any Car Following	High	High

B) Freeway

	Mean Number of Vehicles in Field of View During Trial: 5 4	>4
No Car Following	Low	High
Any Car Following	High	High

Appendix E: Subject Debriefing Guide - Task 7

APPENDIX E - SUBJECT DEBRIEFING GUIDE- Task 7

1. Did you have any difficulties during the run? [Probe for difficulties in driving the truck or in executing the tasks asked by the experimenter.]

No	N=9
Vibration on CRT caused letters to be blurry	
Could not see right side mirror	
Reaching and dialing the phone was difficult	
Wears glasses to read instruments but not normally when driving	
Had hard time shifting gears	
Could not see right fender mirror	
Seat position not great	
Headlights are not angled right	
Put CRT in the dash - this would be better placement	
Took time getting used to the phone	N=3
Difficult to see the numbers on phone - not bright enough	
Finding the radio station with the sun in your eyes	

2. I would like to get your reaction to several of the segments in the run we made today in terms of the driving workload you experienced. Please rate each the following segments on a scale of 0 to 100, where 100 represents the worst workload you typically experience when working. -

a. Driving on I-270 northbound in daylight

Mean Response: 12.3

5	N=2
10	N=8
20	N=4
15	

b. Driving on SR-161 in daylight

Mean Response: 28.5

10	N=3
12	
15	
20	N=3
55	
65	
	N=2
50	
40	N=2

c. Driving on I-270 southbound at night

Mean Response: 19.7

5	N=2
10	N=6
20	N=3
50	
30	
60	
25	

d. Driving on SR-161 at night

Mean Response: 39.7

10	N=4
15	
80	
30	N=3
85	N=2
60	
70	
50	

Note: Subject 1 did not receive the same debriefing guide as the remaining 15 subjects. Therefore, totals sume to 15.

3. During the run we gave you special tasks involving the display and the telephone. For each task I will read to you, I would like you to rate how much workload each one added to the driving task. Use a scale from 0 to 100, where 0 represents no additional workload and 100 represents a large amount of additional workload.

a.	Reading a 2 line message on the CRT	5	
		2	
		80	
		15	
		10	N=8
		60	
		50	N=2
b	Dialing the telephone number stored in memory (e.g., RCL 2 SND)	5	N=2
		3	
		50	N=2
		10	N=4
	Mean Response: 19.5	35	N=2
		20	N=2
		15	N=2
c	Manually dialing a long digit phone number	5	N=2
		50	N=2
		15	
		45	N=3
	Mean Response: 27.3	10	N=2
		35	N=2
		20	N-3
d	Holding a phone conversation when you need to think (e.g., calculating travel time or gallons of fuel needed).	5	
		7	
		50	N=2
		15	N=2
		30	N=2
		65	
		10	N=3
	Mean Response: 25.5	20	
		40	
		25	

{NOTE TO EXPERIMENTER: If the driver needed an example, use "Reading the speedomoter while driving."]

4. Earlier you told me that driving on [See answer to Q2] involved the highest driving workload for you of the four segments I mentioned. In fact, you said you would give this rating of [See answer to Q2] on the scale of 0 to 100. If I asked you to [See answer to Q3] while driving on this section of highway, how would you rate the driving workload involved? Use the 0-100 scale, where 100 represents the worst workload you typically experience while working.

25-30		N=3
100		N=2
75-85		N=3
85-90	Mean Response 56.9	
15		N=3
40		N=2
50-60		

5. Do you think the extra driving tasks we gave you are realistic for professional truck drivers? Explain.

Yes, CRT would be helpful	N=3
Yes, practical instruments	N=5
Yes, could be used when driving	N=4
Yes, useful for the road - accident reports	
Yes, useful on the road	N=2
Yes, they are useful but not while driving, would use them at a stop	

6. Do you think the questions we asked you on the phone were realistic for professional truck drivers?

Yes	N=8
No, fuel and time are not figured that way. She uses subtraction/speed/time etc. and you know this information before you leave.	
Some of them - biographical questions - no, mental reasoning - yes	N=2
Yes, good for keeping you busy	N=2
No, not really	N=2

7. Did you have any problems in using the telephone? Explain.

Hanging the phone up at night - need light	N=3
Dialing and hanging up were difficult due to long reach	
No - after learning how to use it	N=8
Not enough light on numbers on the phone	
Head movement is restricted	
It tied up your hand - could not use it for other tasks	
Had difficulty hearing questions (volume up all the way]	N=4

8. Before today, have you ever used a cellular phone?

Once or twice	N=2
No	N=9
Yes, he has one in his car and one in his boat	
Yes, at his part-tune job	
Yes, at a truck stop NOT while driving	
Yes, he owns one	

9. Do you have any other comments for us about our study?

No	N=3
Tasks are no more difficult than normal tasks but need to be done at driver discretion	
Instruments are in a good location	N=2
Do not like driving and using a phone - eyes off the road too much	
Wire system so that the equipment cannot be operated by truck in motion	
All trucks should have a "jake brake"	
Using the phone was scary at first	
Tended to slow down when on the phone	
Seat belt needs a comfort clip	N=2
Hard to read CRT	N=3
Does not like cell phones or how they are used by other drivers	
Give test with drivers "thinking aloud* to let you know what they are thinking while driving	
Did not feel safe driving while on the phone - just because she can do it does not mean it is safe	
Truck needs a tilt steering wheel	

Rating Scale

Simple, over-the-road
freeway driving,
no traffic,
perfect weather

Worst
workload
conditions
you have ever
experienced

| ---------- | -- |

0 10 100

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