SAVE-IT

SAfety VEhicles using adaptive Interface Technology (Task 6b)

Identify Demand Levels of Telematic Tasks

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6.0 PROGRAM OVERVIEW

Driver distraction is a major contributing factor to automobile crashes. National Highway Traffic Safety Administration (NHTSA) has estimated that approximately 25% of crashes are attributed to driver distraction and inattention (Wang, Knipling, & Goodman, 1996). The issue of driver distraction may become worse in the next few years because more electronic devices (e.g., cell phones, navigation systems, wireless Internet and email devices) are brought into vehicles that can potentially create more distraction. In response to this situation, the John A. Volpe National Transportation Systems Center (VNTSC), in support of NHTSA's Office of Vehicle Safety Research, awarded a contract to Delphi Electronics & Safety to develop, demonstrate, and evaluate the potential safety benefits of adaptive interface technologies that manage the information from various in-vehicle systems based on real-time monitoring of the roadway conditions and the driver's capabilities. The contract, known as SAfety VEhicle(s) using adaptive Interface Technology (SAVE-IT), is designed to mitigate distraction with effective countermeasures and enhance the effectiveness of safety warning systems.

The SAVE-IT program serves several important objectives. Perhaps the most important objective is demonstrating a viable proof of concept that is capable of reducing distraction-related crashes and enhancing the effectiveness of safety warning systems. Program success is dependent on integrated closed-loop principles that, not only include sophisticated telematics, mobile office, entertainment and safety warning systems, but also incorporate the state of the driver. This revolutionary closed-loop vehicle environment will be achieved by measuring the driver’s state, assessing the situational threat, prioritizing information presentation, providing adaptive countermeasures to minimize distraction, and optimizing advanced collision warning.

To achieve the objective, Delphi Electronics & Safety has assembled a comprehensive team including researchers and engineers from the University of Iowa, University of Michigan Transportation Research Institute (UMTRI), General Motors, Ford Motor Company, and Seeing Machines, Inc. The SAVE-IT program is divided into two phases shown in Figure i. Phase I spans one year (March 2003--March 2004) and consists of nine human factors tasks (Tasks 1-9) and one technology development task (Task 10) for determination of diagnostic measures of driver distraction and workload, architecture concept development, technology development, and Phase II planning. Each of the Phase I tasks is further divided into two sub-tasks. In the first sub-tasks (Tasks 1, 2A-10A), the literature is reviewed, major findings are summarized, and research needs are identified. In the second sub-tasks (Tasks 1, 2B-10B), experiments will be performed and data will be analyzed to identify diagnostic measures of distraction and workload and determine effective and driver-friendly countermeasures. Phase II will span approximately two years (October 2004--October 2006) and consist of a continuation of seven Phase I tasks (Tasks 2C--8C) and five additional tasks (Tasks 11-15) for algorithm and guideline development, data fusion, integrated countermeasure development, vehicle demonstration, and evaluation of benefits.

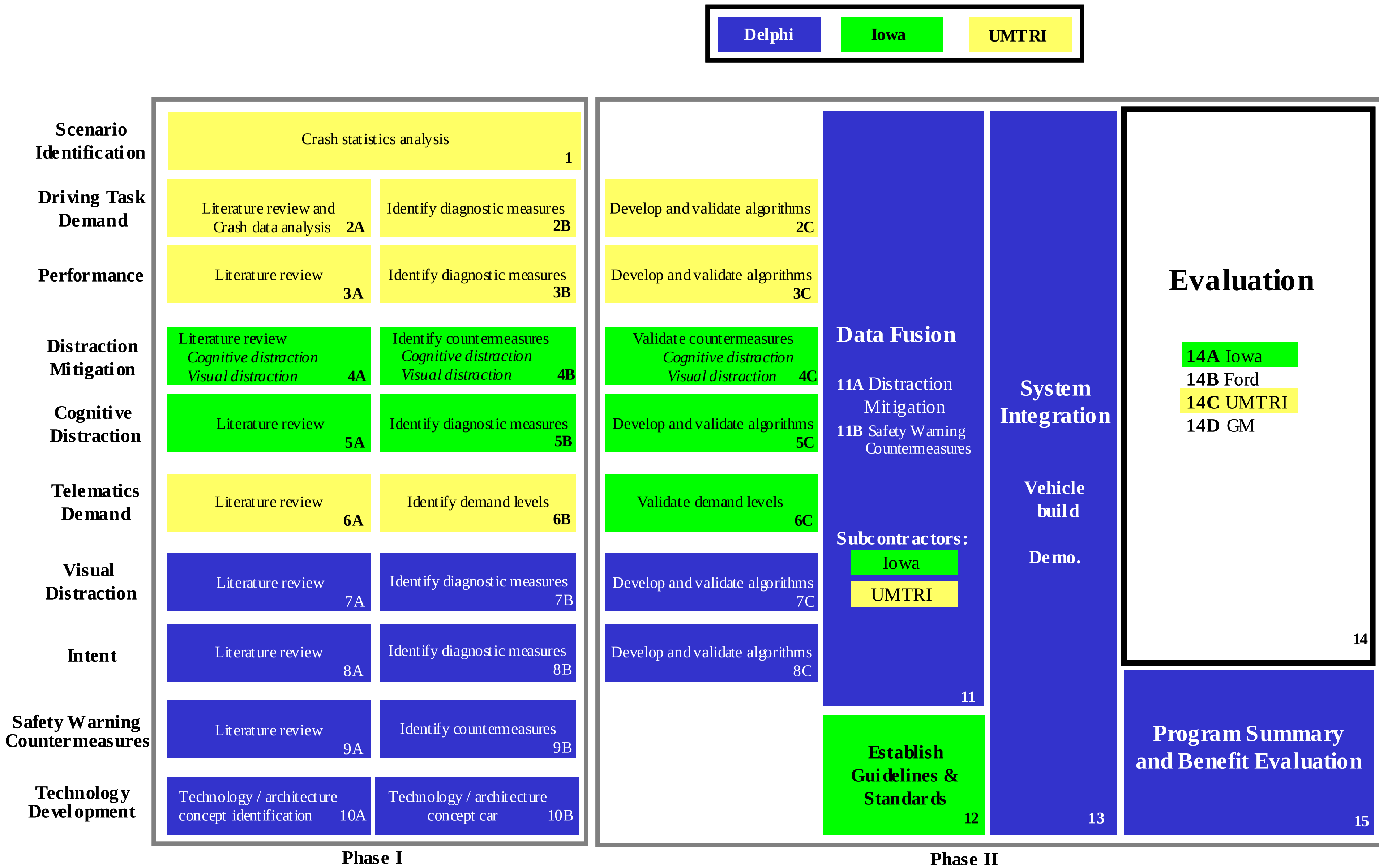

Figure i: SAVE-IT tasks

It is worthwhile to note the SAVE-IT tasks in Figure i are inter-related. They have been chosen to provide necessary human factors data for a two-pronged approach to address the driver distraction and adaptive safety warning countermeasure problems. The first prong (Safety Warning Countermeasures sub-system) uses driver distraction, intent, and driving task demand information to adaptively adjust safety warning systems such as forward collision warning (FCW) systems in order to enhance system effectiveness and user acceptance. Task 1 is designed to determine which safety warning system(s) should be deployed in the SAVE-IT system. Safety warning systems will require the use of warnings about immediate traffic threats without an annoying rate of false alarms and nuisance alerts. Both false alarms and nuisance alerts will be reduced by system intelligence that integrates driver state, intent, and driving task demand information that is obtained from Tasks 2 (Driving Task Demand), 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction), and 8 (Intent).

The safety warning system will adapt to the needs of the driver. When a driver is cognitively and visually attending to the lead vehicle, for example, the warning thresholds can be altered to delay the onset of the FCW alarm or reduce the intrusiveness of the alerting stimuli. When a driver intends to pass a slow-moving lead vehicle and the passing lane is open, the auditory stimulus might be suppressed in order to reduce the alert annoyance of a FCW system. Decreasing the number of false positives may reduce the tendency for drivers to disregard safety system warnings. Task 9 (Safety Warning Countermeasures) will investigate how driver state and intent information can be used to adapt safety warning systems to enhance their effectiveness and user acceptance. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of adaptive safety warning systems and evaluate and document the effectiveness, user acceptance, driver understandability, and benefits and weaknesses of the adaptive systems. It should be pointed out that the SAVE-IT system is a relatively early step in bringing the driver into the loop and therefore, system weaknesses will be evaluated, in addition to the observed benefits.

The second prong of the SAVE-IT program (Distraction Mitigation sub-system) will develop adaptive interface technologies to minimize driver distraction to mitigate against a global increase in risk due to inadequate attention allocation to the driving task. Two examples of the distraction mitigation system include the delivery of a gentle warning and the lockout of certain telematics functions when the driver is more distracted than what the current driving environment allows. A major focus of the SAVE-IT program is the comparison of various mitigation methods in terms of their effectiveness, driver understandability, and user acceptance. It is important that the mitigation system does not introduce additional distraction or driver frustration. Because the lockout method has been shown to be problematic in the aviation domain and will likely cause similar problems for drivers, it should be carefully studied before implementation. If this method is not shown to be beneficial, it will not be implemented.

The distraction mitigation system will process the environmental demand (Task 2: Driving Task Demand), the level of driver distraction [Tasks 3 (Performance), 5 (Cognitive Distraction), 7 (Visual Distraction)], the intent of the driver (Task 8: Intent), and the telematics distraction potential (Task 6: Telematics Demand) to determine which functions should be advised against under a particular circumstance. Non-driving task information and functions will be prioritized based on how crucial the information is at a specific time relative to the level of driving task demand. Task 4 will investigate distraction mitigation strategies and methods that are very well accepted by the users (i.e., with a high level of user acceptance) and understandable to the drivers. Tasks 10 (Technology Development), 11 (Data Fusion), 12 (Establish Guidelines and Standards), 13 (System Integration), 14 (Evaluation), and 15 (Program Summary and Benefit Evaluation) will incorporate the research results gleaned from the other tasks to demonstrate the concept of using adaptive interface technologies in distraction mitigation and evaluate and document the effectiveness, driver understandability, user acceptance, and benefits and potential weaknesses of these technologies.

In particular, driving task demand and driver state (including driver distraction and impairment) form the major dimensions of a driver safety system. It has been argued that crashes are frequently caused by drivers paying insufficient attention when an unexpected event occurs, requiring a novel (non-automatic) response. As displayed in Figure ii, attention to the driving task may be depleted by driver impairment (due to drowsiness, substance use, or a low level of arousal) leading to diminished attentional resources, or allocation to non-driving tasks[1]. Because NHTSA is currently sponsoring other impairment-related studies, the assessment of driver impairment is not included in the SAVE-IT program at the present time. One assumption is that safe driving requires that attention be commensurate with the driving demand or unpredictability of the environment. Low demand situations (e.g., straight country road with no traffic at daytime) may require less attention because the driver can usually predict what will happen in the next few seconds while the driver is attending elsewhere. Conversely, high demand (e.g., multi-lane winding road with erratic traffic) situations may require more attention because during any time attention is diverted away, there is a high probability that a novel response may be required. It is likely that most intuitively drivers take the driving-task demand into account when deciding whether or not to engage in a non-driving task. Although this assumption is likely to be valid in a general sense, a counter argument is that problems may also arise when the situation appears to be relatively benign and drivers overestimate the predictability of the environment. Driving environments that appear to be predictable may therefore leave drivers less prepared to respond when an unexpected threat does arise.

[1] The distinction between driving and non-driving tasks may become blurred sometimes. For example, reading street signs and numbers is necessary for determining the correct course of driving, but may momentarily divert visual attention away from the forward road and degrade a driver's responses to unpredictable danger evolving in the driving path. In the SAVE-IT program, any off-road glances, including those for reading street signs, will be assessed in terms of visual distraction and the information about distraction will be fed into adaptive safety warning countermeasures and distraction mitigation sub-systems.

A safety system that mitigates the use of in-vehicle information and entertainment system (telematics) must balance both attention allocated to the driving task that will be assessed in Tasks 3 (Performance), 5 (Cognitive Distraction), and 7 (Visual Distraction) and attention demanded by the environment that will be assessed in Task 2 (Driving Task Demand). The goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment. For example, as shown in Figure ii, "routine" driving may suffice during low or moderate driving task demand, slightly distracted driving may be adequate during low driving task demand, but high driving task demand requires attentive driving.

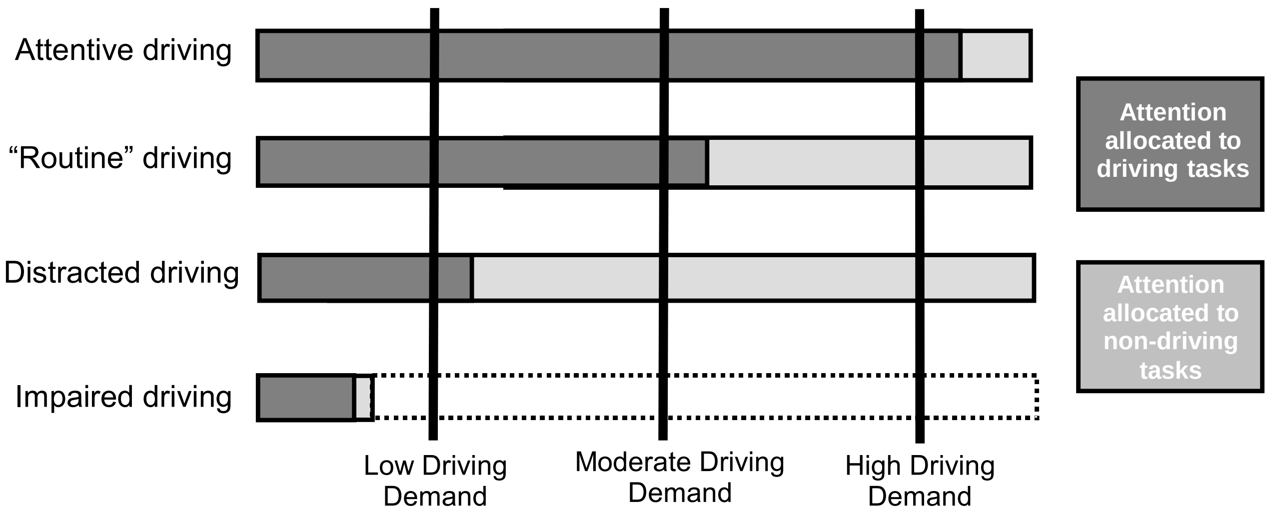

Figure ii. Attention allocation to driving and non-driving tasks

It is important to note that the SAVE-IT system addresses both high-demand and low-demand situations. With respect to the first prong (Safety Warning Countermeasures sub-system), the safety warning systems (e.g., the FCW system) will always be active, regardless of the demand. Sensors will always be assessing the driving environment and driver state. If traffic threats are detected, warnings will be issued that are commensurate with the real time attentiveness of the driver, even under low-demand situations. With respect to the second prong (Distraction Mitigation sub-system), driver state including driver distraction and intent will be continuously assessed under all circumstances. Warnings may be issued and telematics functions may be screened out under both high-demand and low-demand situations, although the threshold for distraction mitigation may be different for these situations.

It should be pointed out that drivers tend to adapt their driving, including distraction behavior and maintenance of speed and headway, based on driving (e.g., traffic and weather) and non-driving conditions (e.g., availability of telematics services), either consciously or unconsciously. For example, drivers may shed non-driving tasks (e.g., ending a cell phone conversation) when driving under unfavorable traffic and weather conditions. It is critical to understand this "driver adaptation" phenomenon. In principle, the "system adaptation" in the SAVE-IT program (i.e., adaptive safety warning countermeasures and adaptive distraction mitigation sub-systems) should be carefully implemented to ensure a fit between the two types of adaptation: "system adaptation" and "driver adaptation". One potential problem in a system that is inappropriately implemented is that the system and the driver may be reacting to each other in an unstable manner. If the system adaptation is on a shorter time scale than the driver adaptation, the driver may become confused and frustrated. Therefore, it is important to take the time scale into account. System adaptation should fit the driver's mental model in order to ensure driver understandability and user acceptance. Because of individual difference, it may also be important to tailor the system to individual drivers in order to maximize driver understandability and user acceptance. Due to resource constraints, however, a nominal driver model will be adopted in the initial SAVE-IT system. Driver profiling, machine learning of driver behavior, individual difference-based system tailoring may be investigated in future research programs.

Communication and Commonalities Among Tasks and Sites

In the SAVE-IT program, a "divide-and-conquer" approach has been taken. The program is first divided into different tasks so that a particular research question can be studied in a particular task. The research findings from the various tasks are then brought together to enable us to develop and evaluate integrated systems. Therefore, a sensible balance of commonality and diversity is crucial to the program success. Diversity is reflected by the fact that every task is designed to address a unique question to achieve a particular objective. As a matter of fact, no tasks are redundant or unnecessary. Diversity is clearly demonstrated in the respective task reports. Also documented in the task reports is the creativity of different task owners in attacking different research problems.

Task commonality is very important to the integration of the research results from the various tasks into a coherent system and is reflected in terms of the common methods across the various tasks. Because of the large number of tasks (a total of 15 tasks depicted in Figure i) and the participation of multiple sites (Delphi Electronics & Safety, University of Iowa, UMTRI, Ford Motor Company, and General Motors), close coordination and commonality among the tasks and sites are key to program success. Coordination mechanisms, task and site commonalities have been built into the program and are reinforced with the bi-weekly teleconference meetings and regular email and telephone communications. It should be pointed out that little time was wasted in meetings. Indeed, some bi-weekly meetings were brief when decisions can be made quickly, or canceled when issues can be resolved before the meetings. The level of coordination and commonality among multiple sites and tasks is un-precedented and has greatly contributed to program success. A selection of commonalities is described below.

<u>Commonalities Among Driving Simulators and Eye Tracking Systems In Phase I</u>

Although the Phase I tasks are performed at three sites (Delphi Electronics & Safety, University of Iowa, and UMTRI), the same driving simulator software, Drive Safety™ (formerly called GlobalSim™) from Drive Safety Inc., and the same eye tracking system, FaceLab™ from Seeing Machines, Inc. are used in Phase I tasks at all sites. The performance variables (e.g., steering angle, lane position, headway) and eye gaze measures (e.g., gaze coordinate) are defined in the same manner across tasks.

<u>Common Dependent Variables</u> An important activity of the driving task is tactical maneuvering such as speed and lane choice, navigation, and hazard monitoring. A key component of tactical maneuvering is responding to unpredictable and probabilistic events (e.g., lead vehicle braking, vehicles cutting in front) in a timely fashion. Timely responses are critical for collision avoidance. If a driver is distracted, attention is diverted from tactical maneuvering and vehicle control, and consequently, reaction time (RT) to probabilistic events increases. Because of the tight coupling between reaction time and attention allocation, RT is a useful metric for operationally defining the concept of driver distraction. Furthermore, brake RT can be readily measured in a driving simulator and is widely used as input to algorithms, such as the forward collision warning algorithm (Task 9: Safety Warning Countermeasures). In other words, RT is directly related to driver safety. Because of these reasons, RT to probabilistic events is chosen as a primary, “ground-truth” dependent variable in Tasks 2 (Driving Task Demand), 5 (Cognitive Distraction), 6 (Telematics Demand), 7 (Visual Distraction), and 9 (Safety Warning Countermeasures).

Because RT may not account for all of the variance in driver behavior, other measures such as steering entropy (Boer, 2001), headway, lane position and variance (e.g., standard deviation of lane position or SDLP), lane departures, and eye glance behavior (e.g., glance duration and frequency) are also be considered. Together these measures will provide a comprehensive picture about driver distraction, demand, and workload.

<u>Common Driving Scenarios</u> For the tasks that measure the brake RT, the "lead vehicle following" scenario is used. Because human factors and psychological research has indicated that RT may be influenced by many factors (e.g., headway), care has been taken to ensure a certain level of uniformity across different tasks. For instance, a common lead vehicle (a white passenger car) was used. The lead vehicle may brake infrequently (no more than 1 braking per minute) and at an unpredictable moment. The vehicle braking was non-imminent in all experiments (e.g., a low value of deceleration), except in Task 9 (Safety Warning Countermeasures) that requires an imminent braking. In addition, the lead vehicle speed and the time headway between the lead vehicle and the host vehicle are commonized across tasks to a large extent.

<u>Subject Demographics</u> It has been shown in the past that driver ages influence driving performance, user acceptance, and driver understandability. Because the age effect is not the focus of the SAVE-IT program, it is not possible to include all driver ages in every task with the budgetary and resource constraints. Rather than using different subject ages in different tasks, however, driver ages are commonized across tasks. Three age groups are defined: younger group (18-25 years old), middle group

(35-55 years old), and older group (65-75 years old). Because not all age groups can be used in all tasks, one age group (the middle group) is chosen as the common age group that is used in every task. One reason for this choice is that drivers of 35-55 years old are the likely initial buyers and users of vehicles with advanced technologies such as the SAVE-IT systems. Although the age effect is not the focus of the program, it is examined in some tasks. In those tasks, multiple age groups were used.

The number of subjects per condition per task is based on the particular experimental design and condition, the effect size shown in the literature, and resource constraints. In order to ensure a reasonable level of uniformity across tasks and confidence in the research results, a minimum of eight subjects is used for each and every condition. The typical number of subjects is considerably larger than the minimum, frequently between 10-20.

<u>Other Commonalities</u> In addition to the commonalities across all tasks and all sites, there are additional common features between two or three tasks. For example, the simulator roadway environment and scripting events (e.g., the TCL scripts used in the driving simulator for the headway control and braking event onset) may be shared between experiments, the same distraction (non-driving) tasks may be used in different experiments, and the same research methods and models (e.g., Hidden Markov Model) may be deployed in various tasks. These commonalities afford the consistency among the tasks that is needed to develop and demonstrate a coherent SAVE-IT system.

The Content and Structure of the Report

The report submitted herein is a final report for Task 6 that documents the research progress to date (March 2003-March 2004) in Phase I. In this report, the major results from the literature review are summarized to determine the research needs for the present study, the experimental methods and resultant data are described, and human factors recommendations are offered.

6.1 INTRODUCTION

The plethora of in-vehicle information systems available now, with more coming rapidly, makes it imperative to manage driver workload imposed by devices within the vehicle (Kantowitz, 2000; Piechulla et al, 2003). The goal of this experiment is to determine how combinations of relatively simple telematic tasks affect driver performance. These secondary tasks have been selected to represent typical mental processes, such as memory and perception, necessary for executing in-vehicle telematic tasks. It is impossible to test all combinations of all potential telematic tasks, especially since new devices are always being added. Thus, a more tractable approach to handling the workload imposed by telematic devices builds upon common mental components. Once the workload of these components is established, task analysis can be used to decompose future telematic tasks based upon these mental elements. This study is the first systematic step toward achieving this objective.

6.1.1 Driver Performance and Driving Scenarios

The fundamental strategy of this experiment is based upon a driving simulator microworld that can be used to design intelligent interfaces that minimize driver distraction (Kantowitz, 2001). The driving scenarios are common to all the SAVE-IT simulator experiments with all project participants in Phase I using the same driving simulator. The key measure of driver performance, again common to all SAVE-IT experiments, is brake reaction time (RT): a leading vehicle decelerates rapidly, forcing the driver to brake. Thus, this experiment is designed to examine the effects of combinations of telematic tasks upon brake RT, although other dependent measures of driving performance are also considered.

Braking response is a common and obvious selection as a dependent measure that has important safety implications for driving and has been widely studied, both in the laboratory and on the road. Consiglio et al (2003) examined the effects of cellular phone conversation, conversing with a passenger, and listening to a radio upon brake RT in a very low-fidelity laboratory driving simulator. While RT for listening to the radio and a no-telematic task control condition did not differ statistically, any kind of conversation caused significant elevation of RT relative to these two conditions. These results are consistent with a theoretical hybrid model of attention and workload that states perceptual inputs are processed in parallel with little drain on capacity whereas response outputs are processed in serial with considerable capacity loading (Kantowitz & Knight, 1976).

Massel and Harbluk (2001) studied effects of cognitive arithmetic tasks upon braking deceleration for drivers on a busy four-lane city road. Performing cognitive tasks resulted in a greater frequency of hard (exceeding 0.3 g) braking events. A difficult arithmetic problem (adding 47+38) resulted in significantly greater frequencies than an easy problem (6+9); both problems resulted in significantly greater frequencies than a no-arithmetic control condition. These results are also consistent with the Kantowitz-

Knight hybrid model since greater response and computational loads are associated with the more difficult arithmetic task.

6.1.2 Telematic Secondary Tasks

Mental workload has long been a useful construct in psychology (e.g., Kantowitz, 1987) and its application to driving has been productive. Kantowitz and Simsek (2000) have critically reviewed secondary-task measures of driver workload. One of their most important conclusions is that many driving studies lack the requisite single-task control conditions to fully evaluate experimental results. An ideal dual-task experiment has the following elements (Kantowitz & Knight, 1976):

- There is a single-task control condition for the primary task
- There is a single-task control condition for each secondary task
- Difficulty or complexity of the primary task is manipulated
- Difficulty or complexity of the secondary task is manipulated.

Mental workload is a theoretical construct. It cannot be observed directly but must be inferred from changes in performance. Kantowitz (1988) has defined mental workload as an intervening variable, similar to attention, which modulates the tuning between the demands of the environment, both within and without the vehicle, and the capabilities of the driver. Changes in performance cannot be evaluated without appropriate control conditions. Thus, driver workload cannot be evaluated properly without the four elements listed above.

The present study includes single-task control conditions for both driving (Driving Only) and telematic tasks (Vehicle Parked). It manipulates the difficulty of the driving primary task by comparing tangent and curved segments of road geometry which have been previously shown to influence driver workload (Kantowitz, 1995). It manipulates the complexity of the secondary task by studying three telematic tasks, performed alone and in concert with the other telematic tasks that are described next.

6.1.2.1 Visual Identification Detection (VID) Task

Detection and identification of stimuli in the visual field has long been associated with studies of driving. Many such studies were reviewed in Task 6a (Green and Shah, 2003). The peripheral detection task (PDT) is a particular exemplar where discrete visual stimuli are randomly presented. For example, Harms and Patten (2003) used a PDT in an on-road study with stimuli presented every 3 to 5 sec and found that visual RT distinguished between using an in-vehicle navigation system versus following a course from memory for a visual message modality but not for an auditory modality.

Almost all driving studies using PDT have a many-to-one mapping of stimuli onto a response. Indeed, Parkes (2004) presenting a workshop on the use of secondary tasks in driving research did not even mention one-to-one mappings until reminded that this might be useful by a member of the audience. In the history of reaction time research, a many-to-one mapping is called a Donders A reaction (or simple reaction) and a one-to-one mapping is called a Donders B reaction (or choice reaction). These are not equivalent tasks and selection of either one should be based upon theoretical reasons, not just practical issues that make it simpler to instrument a Donders A reaction. Many textbooks explain the theoretical differences between these two tasks (e.g., Kantowitz, Roediger & Elmes, 2001, chapter 8).

From the perspective of the Kantowitz-Knight hybrid model, the A reaction requires less capacity because it is less complex and contains zero bits of response information. This suggests that for driving conditions with low workload, the A reaction secondary task may not impose sufficient secondary load to be sensitive to changes in overall driver workload. For example, the auditory results of Harms and Patten (2003) while most likely due primarily to the change in modality might also be in part accounted for by the use of an easy Donders A reaction for the secondary task.

This experiment uses a simplified PDT task with only two visual stimuli presented infrequently. Furthermore, both Donders A and B reactions are implemented for the VID task to evaluate the hypothesis that the B reaction might reveal greater RT as driver workload is increased.

6.1.2.2 Delayed Recall Task

This task requires drivers to memorize a seven-digit phone number presented auditorally. Auditory presentation is used to minimize perceptual conflict with visual telematic tasks and because many new in-vehicle devices use this modality in the belief that presenting non-visual in-vehicle information creates no additional driver workload. Recall is delayed for 30 sec to prevent output interference when combinations of telematic tasks are presented. The driver is required to mentally rehearse the phone number but no overt action is required during the retention interval. This delayed recall task has been used previously in studies of driver workload where it was found to be less effective as an indicator of driver workload than immediate recall when only one telematic task was performed (Kantowitz, 1995). However this limitation should be less important in the present multi-task setting. Memory rehearsal is a fundamental cognitive task required by many in-vehicle information systems.

6.1.2.3 Map Reading Task

This task was previously studied by Tsimhoni and Green (2003) who were able to establish calibrated driver loadings based upon glance durations required by different version of the task. In addition to having obvious face validity, since in-vehicle navigation systems are capable of presenting visual maps for the driver to scan, this task illustrates cognitive loading that has been scaled by earlier research. The task requires a vocal response, which differs from the manual response required by the VID task.

6.2 METHOD

Participants drove a simulator on rural roads with a 45 mph speed limit. The roads consisted of tangents and curves of two different radii. The participants were asked to safely follow a lead vehicle. While following the lead vehicle, participants were asked to perform certain secondary tasks (Map Task, Delayed Recall, and Visual Identification/Detection). Each participant completed two short practice driving scenarios to become familiar with the simulator followed by four 16 minute driving scenarios and one 7-minute driving scenario. Detailed measures of driving performance and secondary task performance measures were recorded and analyzed.

6.2.1 Participants

There were 32 licensed drivers equally divided between Young (aged 20-25 years) and Middle (aged 35-55 years) age who participated in the study. There were 17 male and 15 female participants. Participants were recruited from an advertisement placed in a local newspaper. Participants were paid $40 for a 2-hr session. Participants reported driving between 4,000 and 30,000 miles per year.

6.2.2 Apparatus

6.2.2.1 Driving Simulator

The UMTRI Drive Safety Research Simulator was used for this study. HyperDrive Authoring suite version 1.6 was used for creating the virtual worlds. The user interface for the simulator runs on a Windows PC, which communicates with a host computer running Linux, and four other Linux computers, 1 per image channel. The simulator has a full size vehicle cab with a computer-controlled, projected LCD speedometer/tachometer cluster, operating foot controls, automatic transmission, and torque motor to provide realistic force feedback. The in-cab displays are controlled by Macintosh computers running BASIC, software that can also generate directional in-cab sounds. Those sounds are presented by a 10-speaker system from a Nissan Altima, supplemented by a 4-speaker system for road sounds. Road scenes are projected on three forward screens almost 16 feet from the driver (40 degree field of view for each screen yielding a total 120 degree field of view) and a rear channel 12 feet away (40 degree field of view). Each channel is 1024x768 and updates at 60 Hz. Driver and vehicle performance (steering wheel angle, speed, deceleration, etc.) are recorded at up to 30 Hz by the main simulator computer.

6.2.2.2 Roads

The test scenario consisted of 2-lane rural roads with no oncoming traffic. Participants were asked to maintain a speed of 45 mph while following a lead vehicle. The lead vehicle would brake at certain predetermined locations. The Road Geometry consisted of 14 curves (Figures 6.1, 6.2): 7 moderate curves (400m radius) and 7 hard curves (300m radius). The curves were connected by tangents and there were 14 such straight segments in the scenario. All simulated roads had two lanes with lane widths of 3.6m measured from the center of the roadway to the center of edge line. All the roads included white edgelines. The pavement was gray, and the roads included shoulders that were 3m wide with same color as the pavement. Based on a study by Tsimhoni and Green (2001), the simulated roads were designed to impose two levels of workload by varying road geometry.

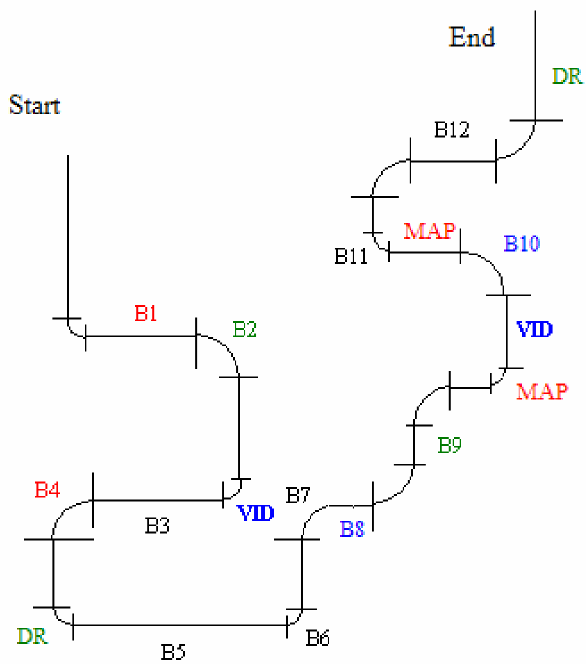

Figure 6.1 Route A used in the Study

Braking Events: B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12

Note that 6 Braking Events have associated Telematic Tasks, 6 Braking Events have no Telematic Tasks

Visual Identification/Detection (VID): B5,B10,RT

Map Task (MAP): B1,B4, MAP

Delayed Recall (DR): B2, B9, DR

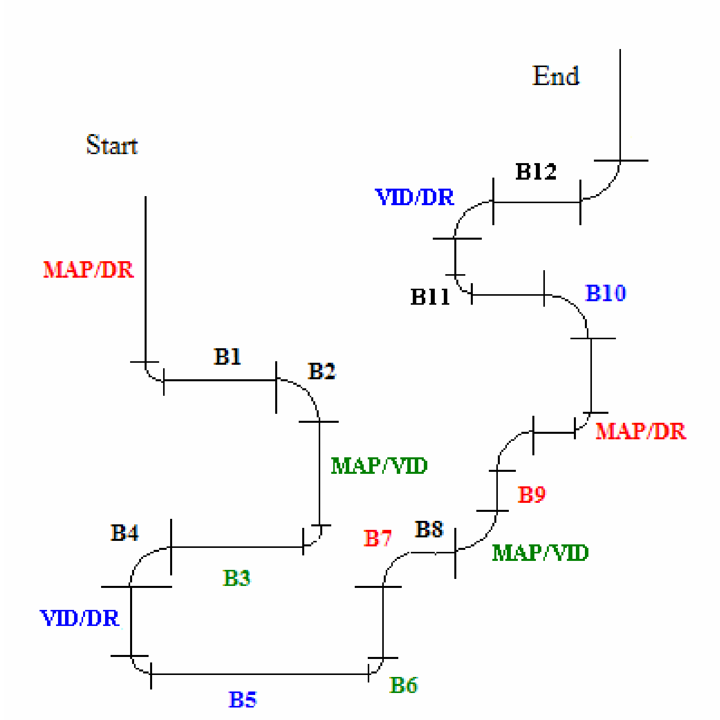

Figure 6.2 Route B used in the Study

Braking Events: B1,B2,B3,B4,B5,B6,B7,B8,B9,B10,B11,B12

Note that 6 Braking Events have associated Telematic Tasks, 6 Braking Events have no Telematic Tasks

Map Task + Visual Identification/Detection (MAP/VID) : B3, B6, MAP/RT

Map Task + Delayed Recall (MAP/DR): B7, B9, MAP/DR

Visual Identification/Detection + Delayed Recall (VID/DR): B5, B10, RT/DR

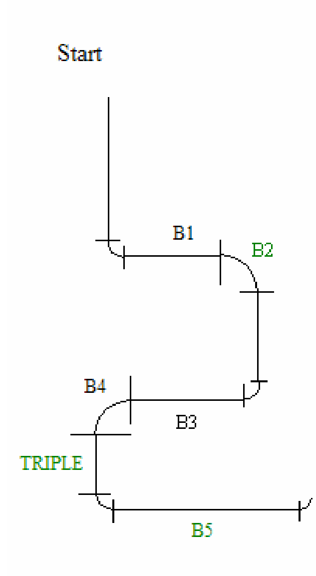

Figure 6.3 Route C used in the Study

Braking Events: B1, B2, B3, B4, B5

Note that 2 Braking Events have associated Telematic Tasks, 3 Braking Events have no associated Telematic Tasks.

Combination of all three telematic tasks: B2, B5, TRIPLE

6.2.2.3 Map Display

A 13-inch touch-screen display, located in the center console of the vehicle, was used to simulate the display panel of a navigation system (Figures 6.5, 6.6). To reduce the active area to a size more likely for a production vehicle; a rectangular 7-inch diagonal opening (4:3 horizontal to vertical ratio) was cut into a black cardboard cover. The center of the touch screen was 23±2 degrees below the horizontal line of sight and 30±2 degrees to the right of the center.

As seen in Fig 6.4 the maps displayed contain a pointer, which represented the heading of the car. In addition, nine icons were used to represent three different Fast food outlets, Motels and Gas Stations.

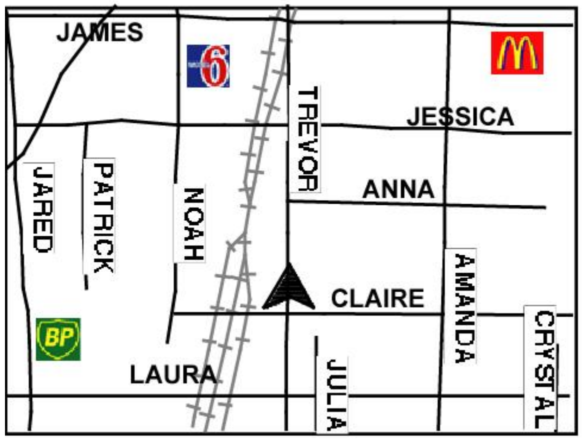

Figure 6.4 Example of the Map display

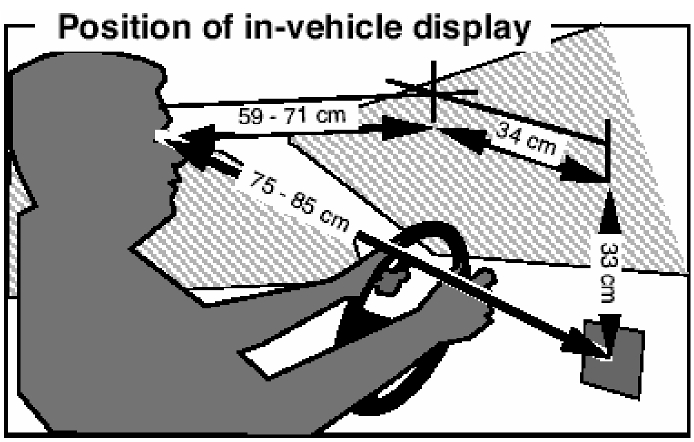

Figure 6.5 Position of in-vehicle display

Figure 6.6 Drivers view of the Map display

6.2.2.4 Visual Detection / Identification Controller

Two high-intensity red LEDs (Marktech 10mm Ultra Bright) were mounted on the windshield. The left LED was located in the driver's foveal line of sight when the driver was looking straight ahead. The right LED was symmetrically located in front of the passenger seat. LEDs remained illuminated for a maximum of 10 sec or until the driver responded. The response of the driver was recorded through one (A reaction) or two (B reaction) push buttons. One push button was located on the steering wheel, close to the right thumb and the other button was located on the steering wheel close to the left thumb.

The LED illumination and recording of the driver response were accomplished using a software application developed specifically for this purpose. Figure 6.7 shows the graphical user interface of this tool developed using Visual Basic. This application enabled the experimenter to control which LED to illuminate (Left, Right), the duration the LED remains illuminated (10 sec) and the response of the participant to the LED (measured in milliseconds).

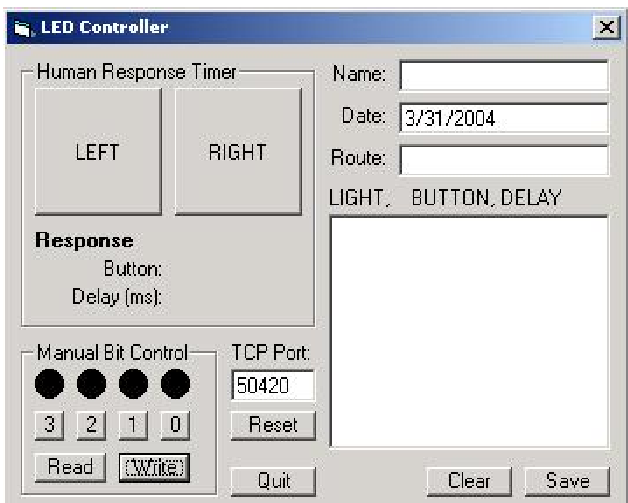

Figure 6.7 LED Controller

6.2.2.5 Delayed Recall

In the delayed recall task, the speaker system in the driving simulator was used to present the in-cab sounds. Auditory stimuli such as 'Telephone Number', followed by a 7-digit number, and 'Say Telephone', cueing the driver's vocal response, were presented. A 30 sec retention interval separated presentation from recall.

6.2.3 EXPERIMENTAL DESIGN

6.2.3.1 Driving Scenarios

Participants were asked to perform three distinct telematic tasks. The telematic tasks were:

1. Map Reading task(MAP)
2. Visual Identification/Detection(VID)
3. Delayed Recall (DR)

These telematic tasks were presented to the driver either singly or in combination. The participant had to complete four driving scenarios or routes (Table 6.1). The driving scenario ‘Practice’ was included solely for the participants to familiarize themselves with the driving simulator and hence did not contain any telematic tasks. Driving scenarios A and B contained 12 instances where the lead vehicle braked. The lead vehicle braking event was set according to the following parameters: (1) Deceleration Rate = 0.2g., (2) Headway = 1.8 Sec., and (3) Braking Event Duration = 5 Secs. Driving Scenario A contained 2 trials for each telematic task(total of 6 events:3x2) with braking and 2 matched trials without braking(Table 6.2). Driving Scenario B contains 2 trials for each pair-wise combination of telematic tasks (total of 6 events: 3x2) with braking and 2 matched trials without braking. The trials were equally distributed along tangents and curves for these scenarios. Driving Scenario C contained 2 trials for the combination of all three telematic tasks with braking and one trial without braking.

Participants experienced scenarios Parked and C once and twice each for scenarios A and B. The Parked scenario presented single telematic tasks without driving and occurred after the Practice scenario. The roadways were driven in reverse direction (from end to start) for alternate scenarios to prevent the participants from becoming familiar with the location of the braking events. During the experimental session the order in which the participants had to complete the scenarios was either ABBAC or BAABC. Order was randomly distributed among the participants.

Note that due to time restrictions during testing, scenario C was shorter and events were not completely balanced. Therefore, this scenario was always presented at the end of the experiment to examine possible effects of encountering all three telematic tasks simultaneously without influencing other combinations of telematic tasks. Scenario C thus represents a pilot experiment to determine if additional research with triples of telematic tasks would be worthwhile. Results from scenario C should be interpreted with caution and will require replication.

Scenario	Number of Telematic Events	Braking Events	Telematic Tasks
Practice	-	-	-
A	12	12	Single
B	12	12	Pairwise Combination
C	3	5	3 Simultaneous

Table 6.1 Driving Scenarios

	Scenario		
	A	B	C
Events			
Braking			
VID	2		
MAP	2		
DR	2		
VID/MAP		2	
VID/DR		2	
MAP/DR		2	
TRIPLE			2
No Braking			
VID	2		
MAP	2		
DR	2		
VID/MAP		2	
VID/DR		2	
MAP/DR		2	
VID/DR/MAP			1

Table 6.2 Distribution of Telematic Tasks across Driving Scenarios.

This study examined 16 (Table 6.3) combinations of 8 telematic tasks (No telematic task, VID, MAP,DR, VID/MAP, VID/DR , MAP/DR and TRIPLE) with 2 levels of road geometry (straight, curve).

		Telematic Task							
		None	VID	MAP	DR	VID/MAP	VID/DR	MAP/DR	TRIPLE
Road Geometry	Straight	√	√	√	√	√	√	√	√
	Curve	√	√	√	√	√	√	√	√

Table 6.3 Levels of Telematic Task and Road Geometry.

Participants in each age group were randomly assigned to one of two Order groups. The first group completed the scenarios in the order ABBAC and the second group completed the task in the order BAABC. Age and Order were between-subject variables.

6.2.4 PROCEDURE

Participants were given informed consent forms to sign and a brief questionnaire as approved by the University of Michigan IRB- Behavioral Science Committee. Instructions were given to the participants. Before proceeding to the main driving scenarios, participants were instructed to adjust the seating position to what they perceived to be an ideal seating position. Participants were also requested to drive as they normally would on a real road maintaining a speed of 45mph. Participants were also required to have their seat belts fastened for the duration of the study.

Two practice scenarios (Table 6.4) were presented to each participant to complete before proceeding to the main driving scenarios. Each session lasted approximately 7 minutes. After the practice session the participants were given a short break and then the telematic baseline Parked scenario was presented. In this scenario, the driving task was absent; participants were seated in the normal driving position and were asked to perform the telematic tasks. Instructions were given on how to perform the telematic tasks. Each telematic task is described below.

Practice 1	7 minute familiarization with no telematic tasks
Practice 2	Repeat of Practice 1
Telematic Baseline	Vehicle Parked. Single telematic tasks
Driving A or B A= Combo Telematic B= Single Telematic	16 minute driving plus braking events plus telematic events
Driving B or A	Replication of previous scenario in other direction
Driving B or A	16 minute driving plus braking events plus telematic events
Driving A or B	16 minute driving plus braking events plus telematic events
Driving C C= 3 Telematic Tasks	7 minute driving plus braking plus telematic events

Table 6.4 Sequence of Scenarios

6.2.4.1 Map Reading Task (MAP)

This task is based upon work of Tsimhoni and Green (2001) who studied glance duration for a variety of map tasks. A map was presented on an LCD screen mounted on the dash. Each map contained 3 different icons, which represented a gas station, motel and a fast food joint (Fig 6.8).

Figure 6.8 Icons used in the Maps

A black pointer indicates the Vehicle position in the map (Fig 6.9). While driving through the route the LCD screen remained blank. When the MAP task was associated with lead vehicle braking, the map was displayed on the LCD screen at the same instant the brake lights of the lead vehicle were illuminated. Participants were told that the map would appear on the screen while driving; they were also instructed that they would not be told as to when the Maps would appear, and hence they were requested to be alert for maps being displayed on the screen. As was done in the parked condition, participants were required to locate the icon farthest away form the car in the map. Response to the MAP task was auditory and was scored for accuracy and latency. A blank screen replaced the map once the participant's response was recorded. If the participants failed to respond within 10 secs, a blank screen replaced the map after 10 secs and the response was recorded as a miss.

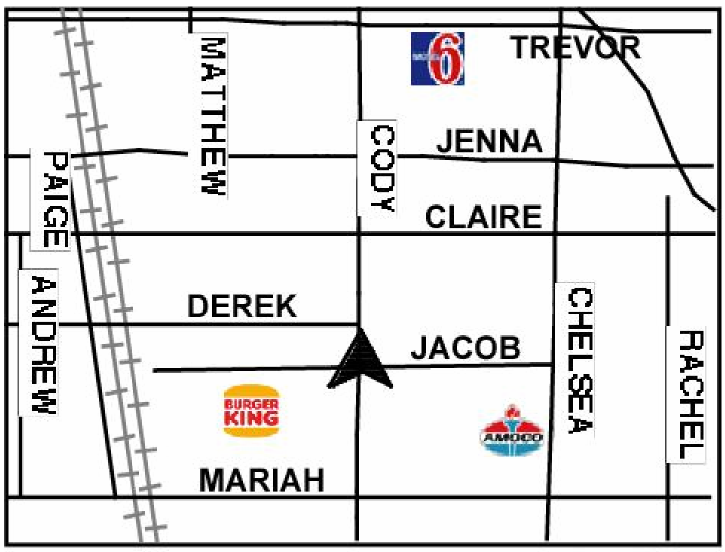

Figure 6.9 Example of the Map used in the MAP Task

In Figure 6.9, Motel 6 is farthest away from the vehicle. A correct response would be 'Motel 6'. The MAP task was presented to the driver 4 times during Route A (Single Telematic), 4 Times in combination with VID task and 4 times in combination with DR task in Route B (pairwise combination). In Route C (Triple Telematic) the MAP task was presented 3 times in combination with the VID and DR task.

6.2.4.2 Visual Identification / Detection (VID)

While driving through the scenarios at predetermined locations any one of the 2 high-intensity LEDs (Left or Right) was illuminated. The LEDs were illuminated as soon as the brake lights of the lead vehicle were illuminated (at the onset of a Braking Event). The LED remained illuminated for a maximum of 10 secs or until the participant responded by pressing a button located on the steering wheel. As soon as the participant responded the LED was extinguished. The reaction times of the participants to LED onset were recorded. The LED remained extinguished until the next VID event. If the participant failed to respond after 10 secs, the LED was extinguished and the response was recorded as a miss.

In the detection task (Donders A reaction) the participant responded by pushing the right button located on the steering wheel, regardless of which LED was illuminated. In the identification task (Donders B reaction), the participant responded by pressing one of the two buttons (Left or Right) located on the steering wheel corresponding to which LED was illuminated. Identification versus Detection was a between-subjects variable to avoid possible negative transfer across conditions. Previous research has studied both Visual Detection (Harms & Pattern, 2003) and Identification (Kantowitz, 1995) as measures of driver distraction and workload.

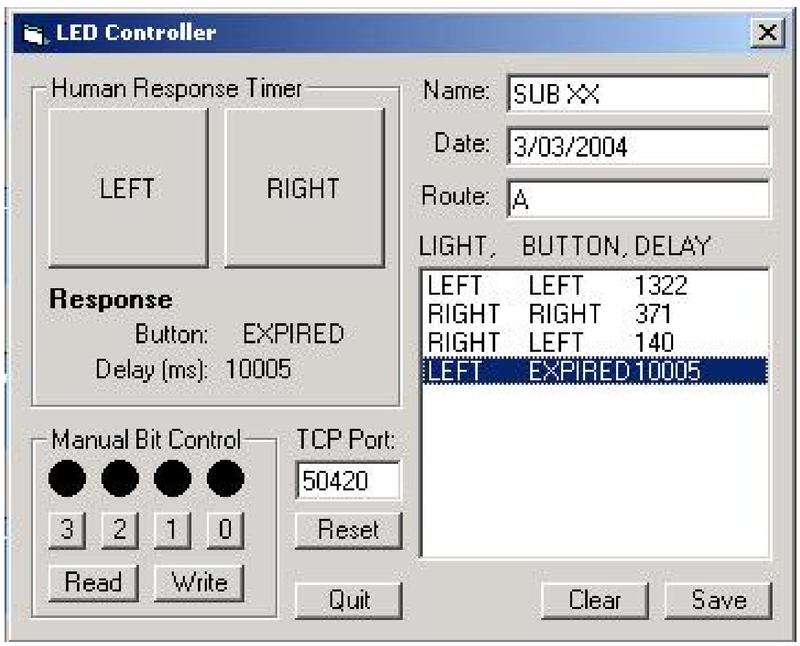

Figure 6.10 Reaction Time Measurements using the GUI

Figure 6.10 shows a sample output from Route A. In this example the participant was given a type B VID task. There are 3 columns in the output section of the GUI. The first column (LIGHT) displays which LED was illuminated (LEFT or RIGHT), the second column (BUTTON) displays the button that was pressed (LEFT or RIGHT). The third column records the reaction time in milliseconds. In the first trial the LEFT led was illuminated and the participant responded by pressing the LEFT button after 1322 milliseconds. In the third trial, the RIGHT LED was illuminated and the participant responded by pressing the LEFT button. In the last trial the participant failed to respond within 10 secs and hence the trial ‘EXPIRED’.

The VID task was presented to the driver 4 times during Route A (Single Telematic), 4 Times in combination with MAP task and 4 times in combination with DR task in Route

B (pairwise combination). In Route C (Triple Telematic) the VID task was presented 3 times in combination with the MAP and DR task.

6.2.4.3 Delayed Recall (DR)

Participants were asked to memorize a 7-digit telephone number, which was presented auditorally after they heard a cue word “Telephone Number”. After a 30-sec delay the auditory cue “Say Telephone” was presented and the participants were asked to verbally state the number, which was scored for accuracy of serial recall. When the DR task occurred with lead vehicle braking the onset of the brake lights of the lead vehicle coincided with the end the of the 30 sec retention period. The participants were asked to recall the number as soon as the vehicle in front braked.

Since the response to the Map task was auditory, it was important to avoid output interference when doing the pair-wise combination of the Delayed Recall and Map Task, and the combination of all 3 Telematic tasks. To eliminate output interference the participants were asked to repeat the telephone number 10 secs after the initiation MAP task; participants were given the telephone number 20 secs before the MAP task (Figure 6.11) . Participants were occupied rehearsing the telephone number and did not recall it immediately. DR task was presented to the participant 4 times during Route A (Single Telematic), 4 Times in combination with MAP task and 4 times in combination with VID task in Route B (pairwise combination). In Route C (Triple Telematic) the DR task was presented 3 times in combination with the MAP and VID task.

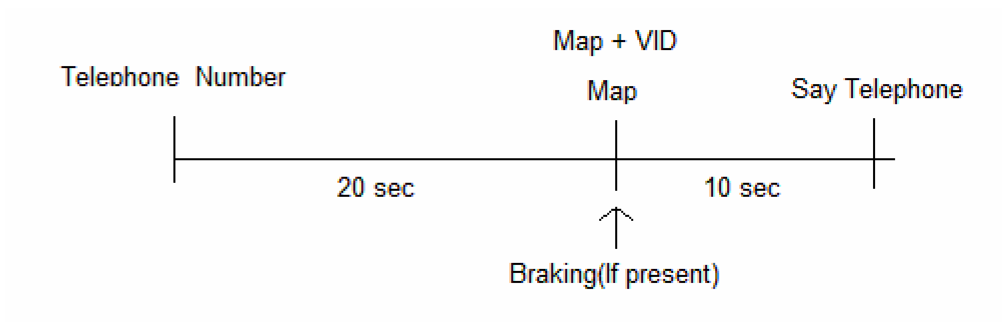

Figure 6.11 Presentation of the DR task (in combination with the map task)

The following driving measures were recorded and analyzed in this study. *SAS software* was used as our data analysis tool.

Brake Response Time

Brake Response Time was defined as the time between the illumination of the brake lights of the lead vehicle and the driver making initial contact with the brake pedal. Brake pedal and accelerator pedal values were recorded continuously across all driving scenarios. Brake and accelerator pedal values ranges from 0-1(0- No Contact with Brake or Accelerator Pedal, 1- Maximum Depression of Brake or Accelerator Pedal). Brake Response Time was calculated as follows:

Brake Response Time (Sec) = Time (Brake Pedal Value >0) - Time (Illumination of Lead vehicle Brake Lights)

Accelerator Release Time

Accelerator Release Time was defined as the time between the illumination of the brake lights of the lead vehicle and the driver releasing his foot completely from the accelerator pedal. Accelerator Release Time was calculated as follows:

Accelerator Release Time (Sec) =Time (Accelerator Pedal Value =0)-
Time (Illumination of Lead vehicle Brake Lights)

Standard Deviation of Lane Position and Steering Angles

Lane position and steering angle were recorded continuously. Starting when telematic tasks were initiated, standard deviations of Lane Position and Steering Angles were calculated for a 5 sec window for each telematic event.

Steering Entropy

Steering Entropy calculations were based on the method developed by Nakayama, Futami, Nakamura & Boer (1999) who demonstrated that Steering Entropy can quantify the workload imposed on drivers who are engaged in activities in addition to driving. *SAS* Macros developed by Harry Zhang at Delphi were used for calculating the Steering Entropy values based upon 60 sec windows.

6.3 RESULTS

6.3.1 DRIVING PERFORMANCE

Five measures of driving performance were analyzed:

- Brake RT
- Accelerator Release Time
- Standard deviation of lateral position
- Standard deviation of steering angle
- Steering entropy

Data were subjected to an analysis of variance (ANOVA) with two between-subject independent variables, Age [Young, Middle] and Order [abba, baab], and two within-subject variables, Road Geometry [Tangent, Curve] and Telematic Task [None, Map, Digit Recall (DR), VID, plus pairwise and triple combinations]. Post-hoc t-tests were performed with alpha = .05 to further evaluate significant ANOVA effects.

6.3.1.1 Brake RT

Figure 6.12 shows Brake RT as a function of Telematic Task. Effects of Telematic Task were statistically significant, $F(7, 420) = 21.7$, $MSe = 12.0$, $p < .0001$. The No-Telematic Task control condition differed significantly from all other conditions, as did the Triple combination of all telematic tasks. The following groupings of Tasks were not significantly different:

[VID, VID/DR, DR]
[Map, Map/DR]
[Map/DR, VID/Map].

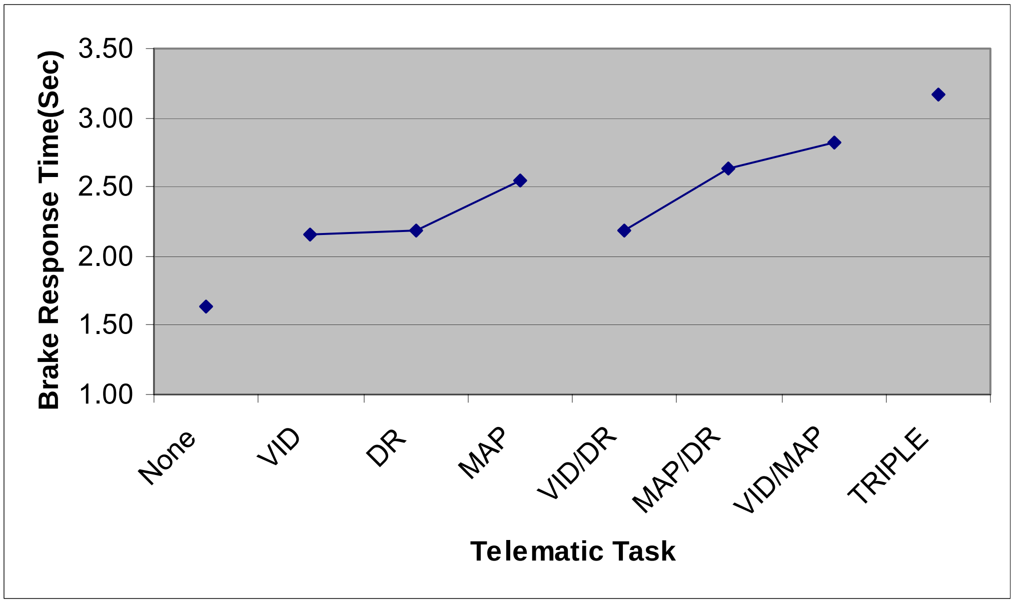

Figure 6.12 Brake response time as a function of Telematic Task.

Brake RT was significantly higher for Curves (2.54 sec) versus Tangents (2.35 sec), $F(1,420) = 5.07$, $MSe = 12.0$, $p < .003$. Brake RT did not differ reliably between Young (2.33 sec) and Middle-Age (2.56 sec) drivers, $F(1, 28) = 2.08$, $MSe = 3.36$, $p > .05$. There were no statistically significant two-way or higher order interactions between Age, Task and Road Geometry.

Figure 6.13 replots these data as a function of number of telematic tasks. Effects of number of telematic tasks were statistically significant, $F(3, 196) = 47.1$, $MSe = 21.1$, $p<.0001$. Post-hoc t-tests showed no significant difference between one and two telematic tasks while, as in the previous analysis, zero and three telematic tasks differed from all other conditions.

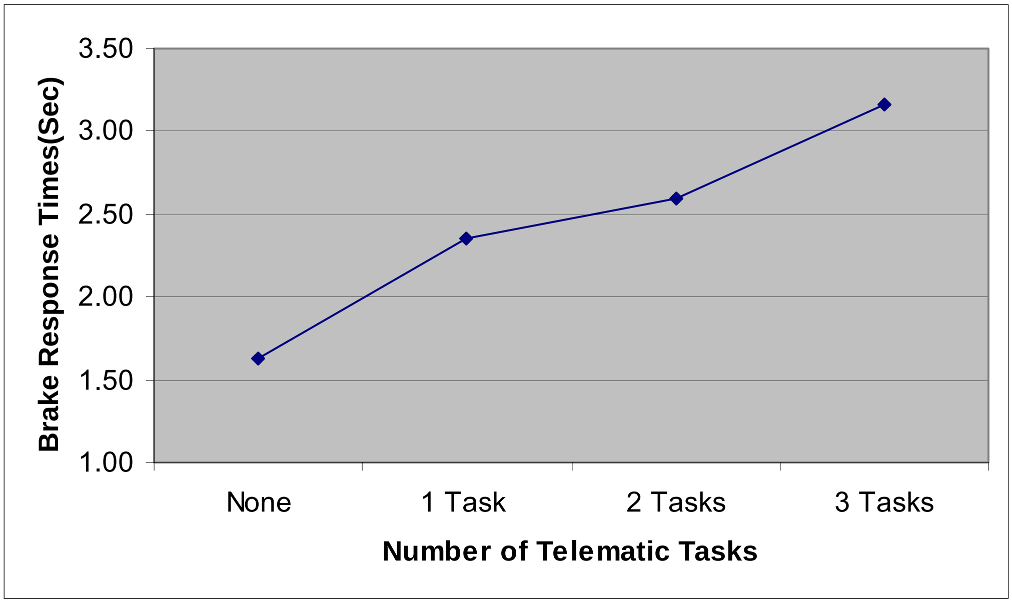

Figure 6.13 Brake response time as a function of number of telematic tasks.

6.3.1.2 Accelerator Release Time

Results for accelerator release time were similar to results for brake RT, although approximately half a second faster. Figure 6.14 plots accelerator release time as a function of Telematic Task. Effects of Task were statistically significant, $F(7, 420) = 26.0$, $MSe = 0.48$, $p<.0001$. The No Telematic Task control condition differed from all other conditions. The following groupings of Tasks were not significantly different:

[VID/DR, VID, DR]
[Map, Map/DR]
[VID/Map, Triple].

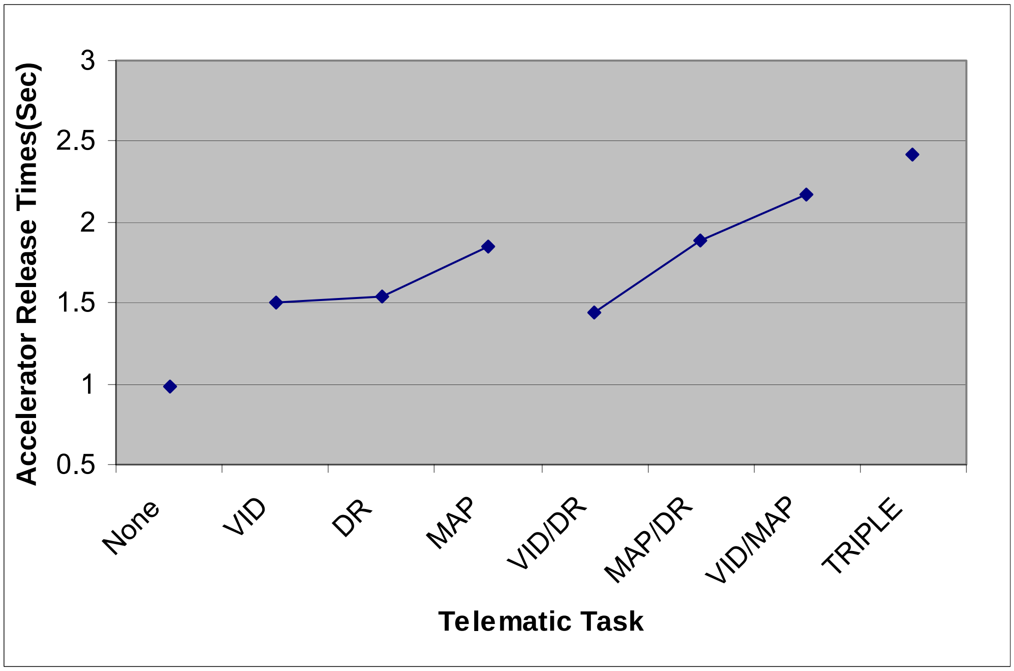

Figure 6.14 Accelerator release time as a function of Telematic Task.

Accelerator release time was significantly higher for Curves (1.86 sec) versus Tangents (1.58 sec), $F(1,420) = 22.0$, $MSe = 0.48$, $p<.0001$. Accelerator release time did not differ reliably between Young (1.65 sec) and Middle Aged (1.79 sec) drivers, $F(1, 28) = 1.72$, $MSe = 1.43$, $p>.05$. There were no statistically significant two-way or higher order interactions between Age, Telematic Task and Road Geometry.

Figure 6.15 replots these data as a function of number of telematic tasks. Effects of number of telematic task were significant, $F(3, 196) = 66.7$, $MSe = 0.315$, $p<.0001$. Post-hoc t-tests showed no significant difference between one and two telematic tasks while, as in the previous analysis, zero and three telematic tasks differed from all other conditions.

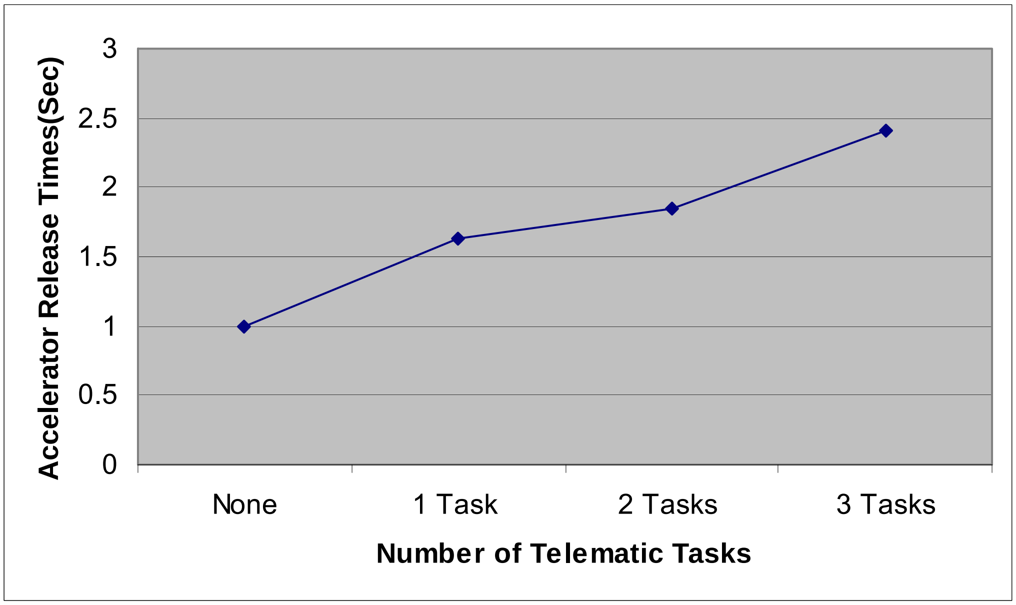

Figure 6.15 Accelerator release time as a function of Number of telematic tasks.

6.3.1.3 Standard Deviation of Lane Position and Steering Angle

Figure 6.16 shows standard deviation of lane position as a function of Road Geometry and Telematic Task. Lane deviation is, of course, higher for Curves than for Tangents, $F(1,420) = 206$, $MSe = 0.00373$, $p< .0001$. There is a significant effect of Telematic Task, $F(7,420) = 7.40$, $p < .0001$, and no significant interactions. Post-hoc t-tests show that the VID/DR task differed from all other tasks. The remaining telematic tasks do not differ, indicating that lane standard deviation is not a useful primary-task measure of workload imposed by in-vehicle tasks. These results agree with those of Kantowitz (1995) who also found that lane standard deviation was not influenced by secondary tasks.

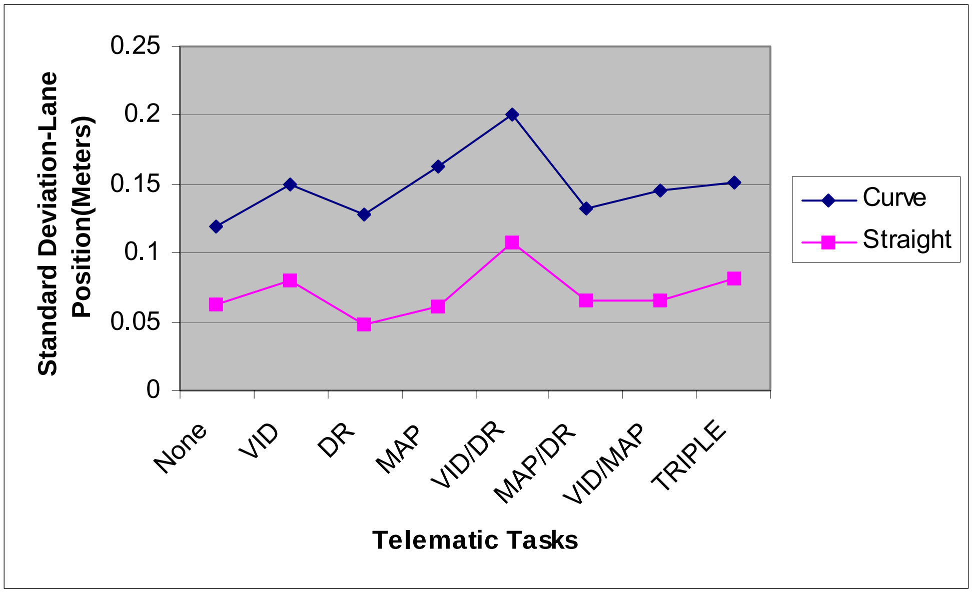

Figure 6.16 Standard deviation of lane position as a function of Telematic Task.

Figure 6.17 shows standard deviation of steering angle as a function of Road Geometry and Telematic Task. Effects of Geometry, $F(1,420) = 195$, $MSe = 2.11$, and Task, $F(7,420) = 8.74$, were significant with $p<.0001$. Of greater interest is the interaction between Geometry and Task, $F(7,420) = 3.84$, $p<.0005$. As telematic task load increased, standard deviation for curves increases more than deviation for tangents. These results differ from those of Kantowitz (1995) who found that steering standard deviation was not influenced by secondary tasks. However, the present experiment used driving scenarios containing both curves and tangents whereas Kantowitz (1995) used scenarios that contained either all curves or all tangents. It seems reasonable to speculate that in the more realistic present scenarios, transitions from tangents to curves generated momentary geometric driver workload that combined non-additively with in-vehicle workload.

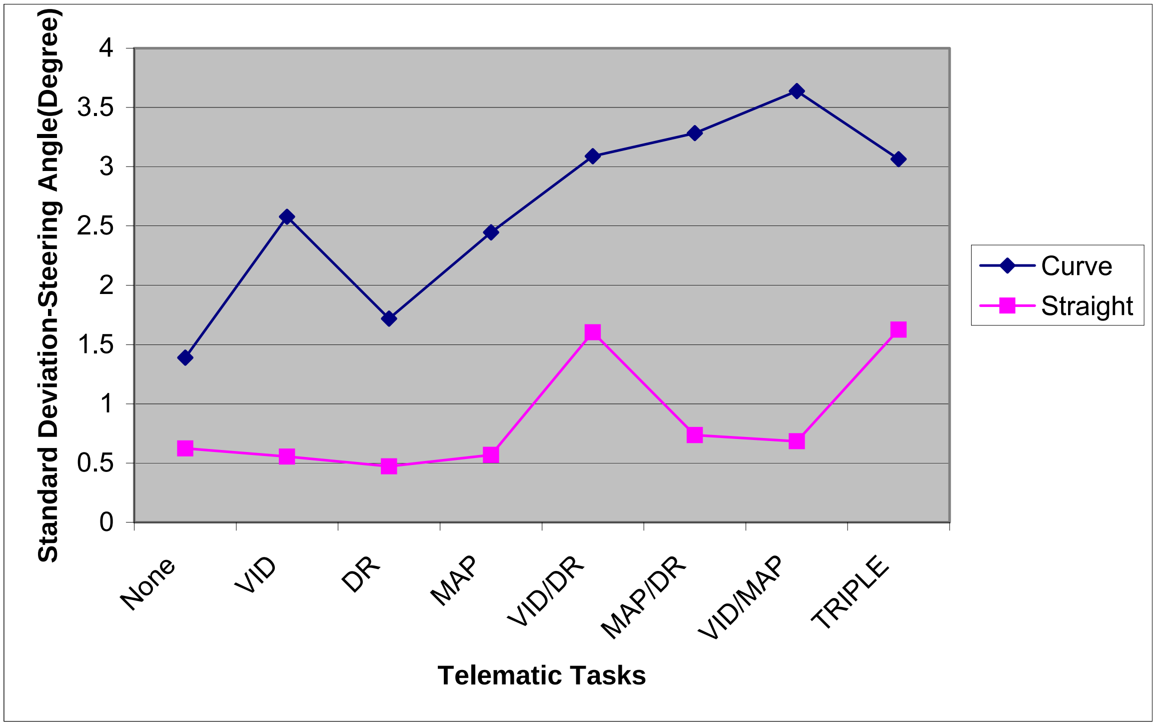

Figure 6.17 Standard deviation of steering angle as a function of Telematic Task.

6.3.1.4 Steering Entropy

Table 6.5 shows steering entropy [Hp] (Boer 2001) calculated in 60 sec epochs, with zero sec the start of a telematic event, as a function of number of tasks. Since a driver will in many cases travel over both tangents and curves in 60 sec, it would not be meaningful to analyze Road Geometry as was done for standard deviation of lane position and steering angle. Effects of Telematic Tasks were significant, $F(7,196) = 9.87$, $MSe = 0.00627$, $p<.0001$.

Task	Hp
None	0.558
Map	0.612
VID	0.568
DR	0.556
MAP/DR	0.642
VID/MAP	0.619
VID/DR	0.642
TRIPLE	0.674

Table 6.5 Steering entropy for each telematic task.

Figure 6.18 shows that steering entropy increases with the number of Telematic Tasks. Effects of number of telematic tasks were statistically significant, $F(3,84) = 22.5$, MSe = 0.08867394, $p<.0001$. Post-hoc t-tests showed no significant difference between None and 1-Task conditions while 2- and 3-Task conditions differed from all other conditions.

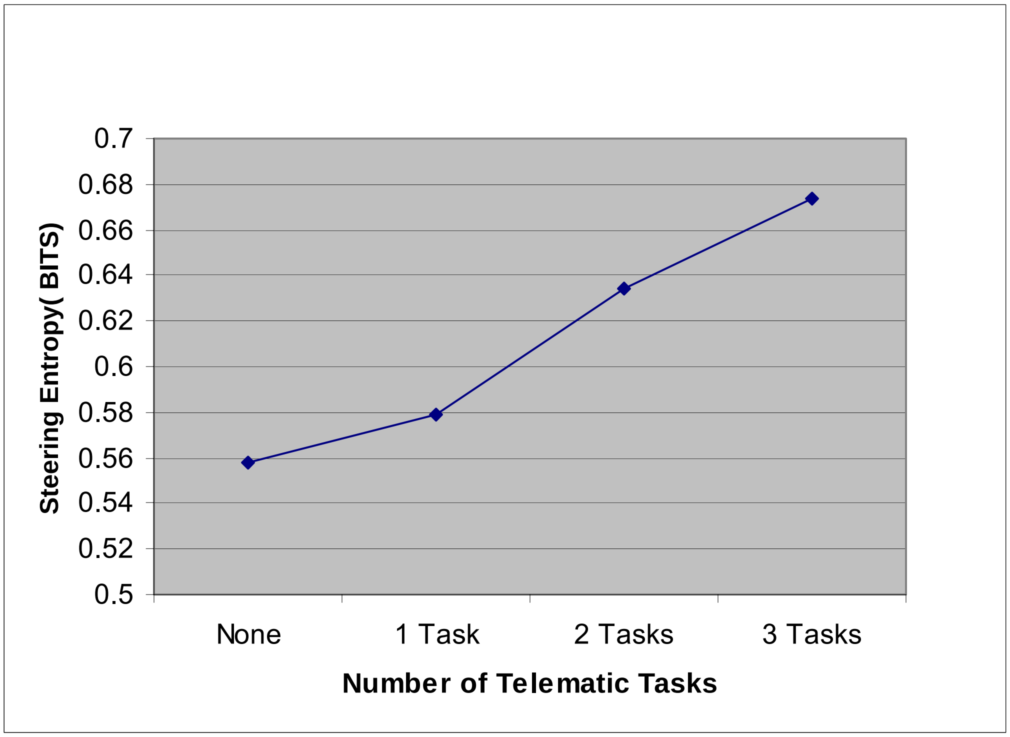

Figure 6.18 Steering entropy as a function of number of telematic tasks.

6.3.2 TELEMATIC TASK PERFORMANCE

6.3.2.1 Visual Identification / Detection (VID) Task

Figure 6.19 shows visual RT as a function of number of other telematic tasks. Effects of Tasks were significant, $F(3, 168) = 33.3$, $p<.0001$. Post-hoc t-tests show that RT for the Parked control condition was significantly less than all other conditions and that the VID+2 condition also differed from all other tasks. There was no significant difference between VID+1 and VID+2 task conditions. Visual RT was greater for Curves (1233 msec) than for Tangents (993 msec), $F(1,168) = 16.5$, $p<.0001$, but there were no interactions between Road Geometry and any other independent variables.

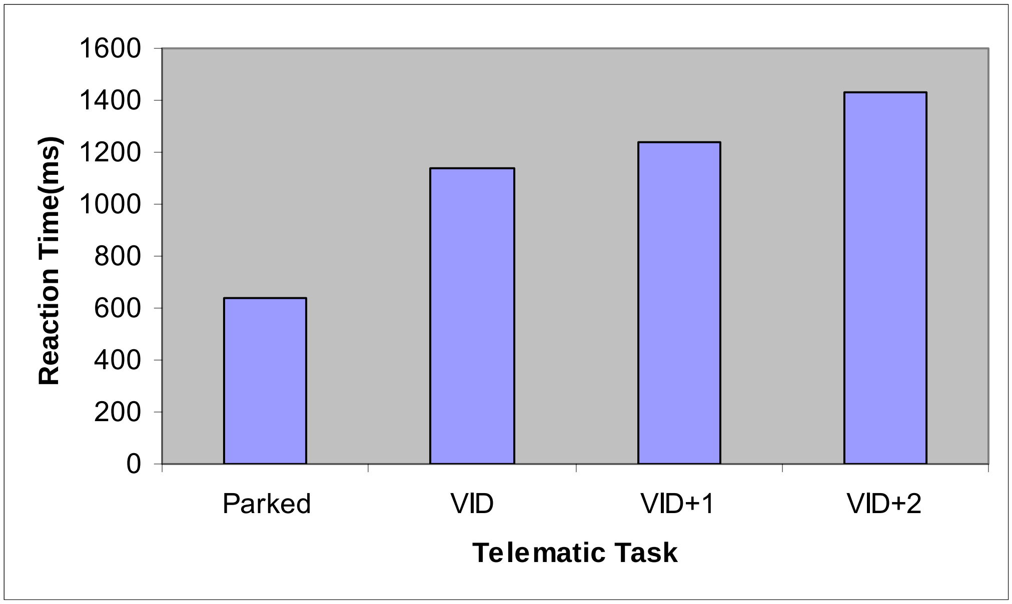

Figure 6.19 Visual reaction time as a function of telematic task load.[Parked = single-task control condition, +1 = visual task plus one other telematic task, +2 = all three telematic tasks]

Figure 6.20 shows visual RT as a function of Type (Donders A or B) of reaction task and number of other telematic tasks. The interaction between Type and number of other Tasks was significant, $F(3, 168) = 3.02$, $p<.03$ but there was no significant main effect of Type, $F(1, 24) = .73$, $p>.05$. Post-hoc t-tests showed the difference between A and B reactions was significant only for the VID+2 condition.

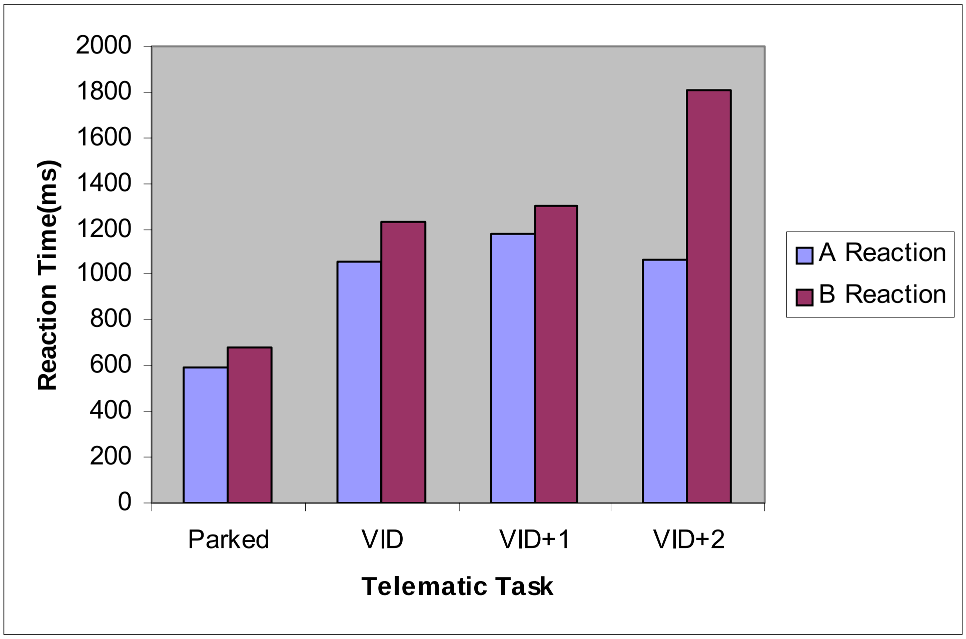

Figure 6.20 Visual A and B reaction times as a function of telematic task load.

6.3.2.2 Digit Delayed Recall Task

Figure 6.21 shows digit recall as a function of driver Age and Task. Effects of Task, $F(3, 196) = 16.1$, $MSe = 212$, and the interaction between Task and Age, $F(3,196) = 7.31$, were both significant, $p<.0001$. Young drivers (84.4%) showed better delayed recall than Middle drivers (67.2%), $F(1, 28) = 7.47$, $MSe = 2541$, $p< .01$. For Young and Middle Age drivers recall did not differ for the Digit+2 condition. This was one of two significant effects involving Age in the entire experiment. Post-hoc t-tests showed the Parked condition differed from all other conditions and the Digit condition also differed from all other conditions. There was no significant difference between Digit+1 and Digit+2 conditions. There was also no significant difference between recall on Curves (76.2%) and Tangents (75.5%), $F(1,196) = 0.21$, $p>.05$.

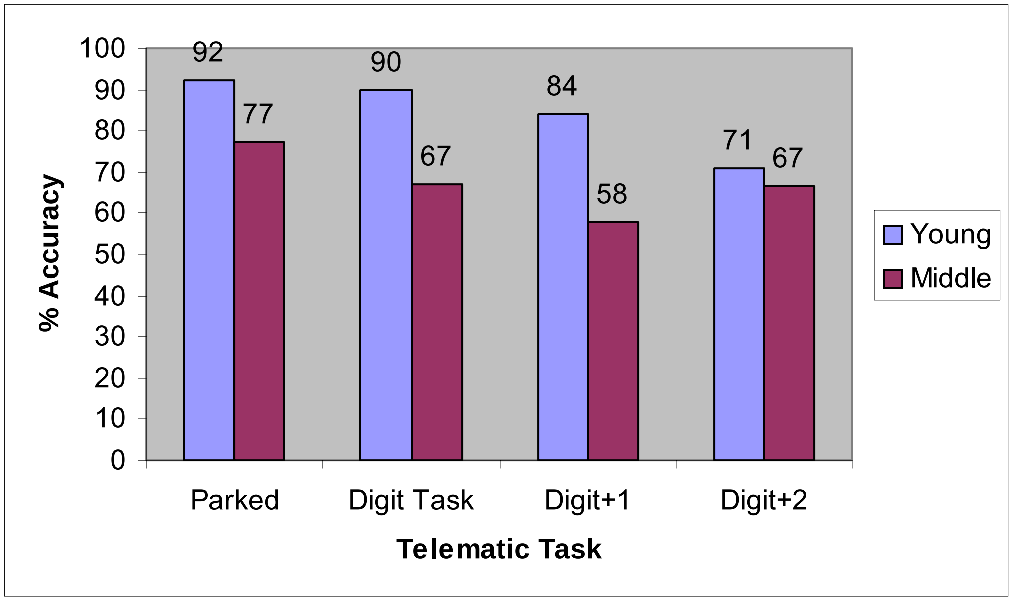

Figure 6.21 Delayed digit recall accuracy as a function of Telematic Task and Driver Age.

6.3.2.3 Map Reading Task

Figure 6.22 shows map reading accuracy as a function of number of other Tasks. Effects of Task were significant, $F(3,196) = 62.2$, $MSe = 209$, $p<.0001$. Post-hoc t-tests showed that the Parked and the Map+2 conditions differed from all other conditions. There was no significant different between Map+1 and Map+2 conditions. No other main effects or interactions were statistically significant.

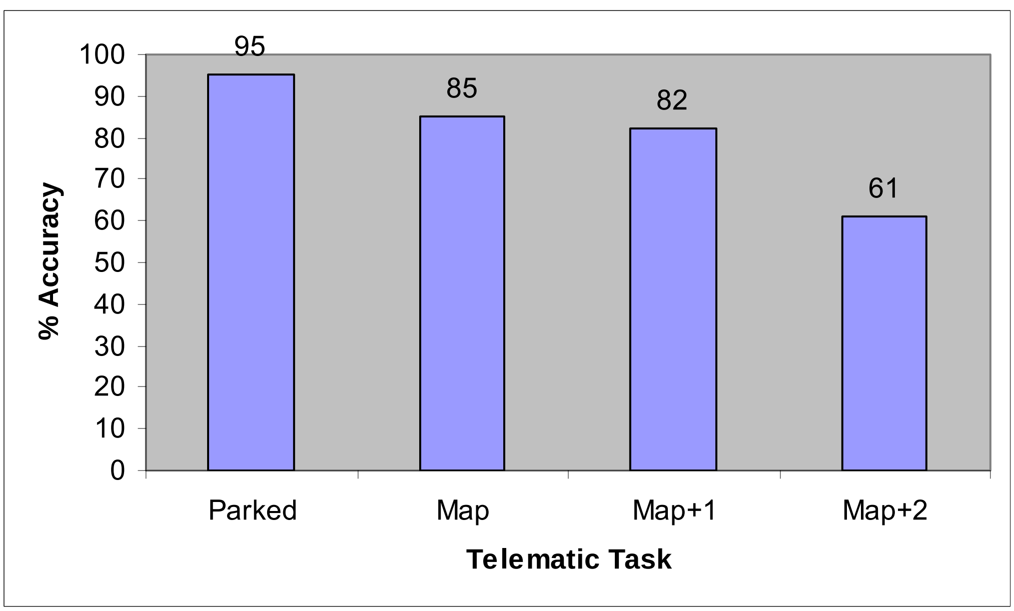

Figure 6.22 Map reading accuracy as a function of telematic task load.

Figure 6.23 shows map reading latency as a function of number of other Tasks and Age. Effects of Task were significant, $F(3,196) = 162$, $MSe = 0.748$, $p < .0001$. Post-hoc t-tests showed that all Task conditions differed significantly from each other. Latency for Young drivers (4.01 sec) was faster than for Middle drivers (4.66 sec), $F(1, 28) = 8.75$, $MSe = 3.09$, $p<.006$. When Parked there was no difference in the latencies of Young and Middle drivers, resulting in a significant interaction between Task and Age, $F(3,196) = 3.80$, $p<.01$. Latency for Curves (4.54 sec) significantly exceeded latency for Tangents (4.13 sec), $F(1, 196) = 14.4$, $p<.0001$.

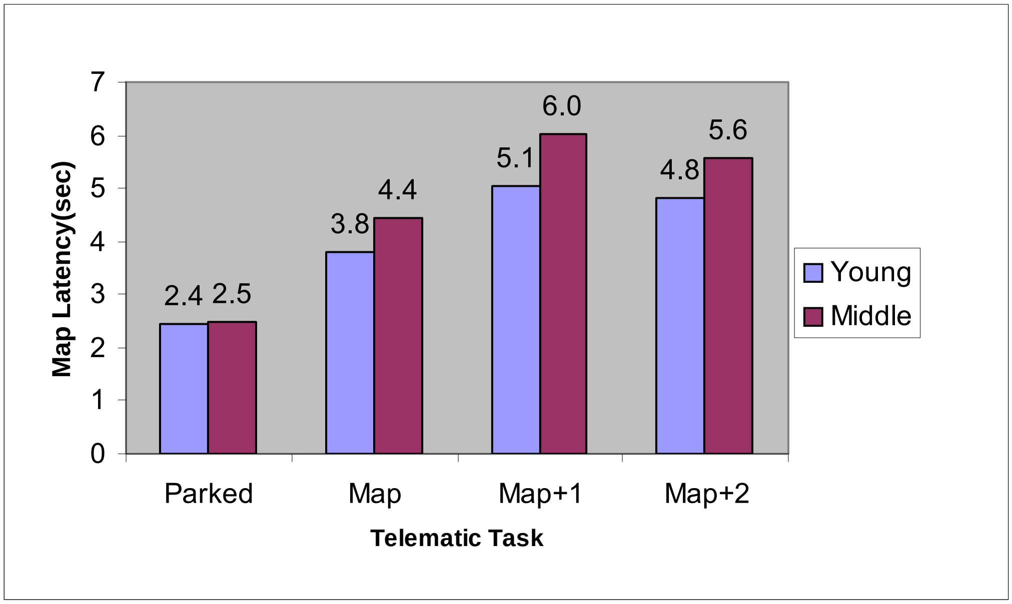

Figure 6.23 Map reading latency as a function of telematic task load.

6.4 DISCUSSION

The pattern of results for both primary and secondary tasks was quite clear. Drivers are unable to perform simple telematic tasks while the vehicle is in motion without suffering decrements on performance of both simulated driving and telematic tasks. Thus, driving safety would be improved by providing a telematic workload manager to control in-vehicle information systems.

6.4.1 Implications for Driving Safety

Telematic tasks can decrease driving performance in two ways. First, direct measures of driving performance are adversely affected by adding telematic tasks. Second, the telematic tasks are themselves performed with some decrement, relative to a parked vehicle, and thus may require repetition before the driver is satisfied. Such repetition increases driver exposure to telematic tasks, which in turn decreases driving performance.

The most important results for driving safety are the increases in brake response time and accelerator release time (Figures 6.12 -6.15). Adding even one telematic task produces an increase of over 0.5 sec. While it is beyond the scope of this experiment to reach conclusions about how much of an increase in brake response time is acceptable to society, some observers might conclude that an increase greater than 0.5 sec is unacceptable so that all telematic devices should be banned in a moving vehicle. However, if one is willing to accept this increase for a single telematic task, then adding a second telematic does not double the time penalty, adding only approximately another 200 msec. Hence a society willing to tolerate the safety effects of adding one telematic task should also agree to adding two simultaneous telematic tasks, provided that only simple telematic tasks, such as were tested in this experiment, are being considered. But even with simple telematic tasks, adding a third telematic task doubles brake response and accelerator release times, with delays of more than 1.5 sec relative to the driving-only control condition. Even an American society willing to tolerate more than 40,000 deaths annually on the road might be reluctant to accept this large time delay.

An important caveat in this discussion is that the telematic tasks studied were simple. More complex tasks, such as sustained conversation and entering data into an in-vehicle system, would be expected to produce at least equal or, more likely, greater delays than obtained in this study. Thus, it would be prudent to repeat this study with complex telematic tasks and with more data being obtained for the triple telematic-task condition.

It is not surprising that the greatest delays were associated with the map reading task. This visual task required more than one glance so that eyes were directed away from the road. There was also more cognitive complexity associated with this telematic task. However, the simple map used in this experiment was typical of that displayed in many in-vehicle navigation systems and the location of the map display was carefully chosen to represent the location of a typical in-vehicle system. This result suggests that navigation systems currently available and in use compromise safety even when no other telematic task is underway. When more than a single telematic task is processed by the driver, delays are greater when one of the simultaneous tasks is map reading.

6.4.2 Telematic Task Performance

All telematic tasks suffered decrements when performed while driving even if only a single telematic task was required. Greater decrements occurred with combinations of telematic tasks (Figures 6.19 – 6.23). Had the driver chosen to maintain the performance level of the telematic tasks, rather than trying to maintain safe vehicle operation as they were instructed during the experiment, there would have been a greater trade-off between secondary and primary tasks, resulting in poorer driving performance. In a two-hour experiment where drivers know they are being observed, many drivers might choose to drive more carefully than they would on the road when selection of telematic tasks derives from the driver's own desires, rather than the dictates of an experimental protocol. Thus, simulator experiments are conservative and may underestimate the safety implications of adding telematic tasks. To the extent that drivers wish to accomplish telematic tasks, even more attention may be diverted from driving. It is impressive that strong effects upon driving performance were obtained in a laboratory. Even stronger effects may be found on the road and field studies of telematic tasks are needed to determine how much stronger, i.e., how much more dangerous are telematic tasks when no experimenter is observing?

6.4.3 Toward a Workload Manager

Results clearly imply that if vehicles are to be operated while drivers are performing simultaneous telematic tasks, a workload manager is needed to minimize decrements in driving performance. A superior workload manager must accomplish several goals:

- Evaluate workload imposed by in-vehicle devices
- Evaluate workload imposed by driving, including traffic and road conditions
- Evaluate driver capability, including fatigue and influence of alcohol and drugs
- Calculate total driver workload
- Establish a red line value for workload based on driver capability
- Control telematic devices when workload is excessive, including inhibiting displays
- Control vehicle functions when workload is excessive, including limiting vehicle speed.

This experiment supports only the first of these key goals.

Workload managers are examples of a larger class of human-machine systems called intelligent interfaces (Kantowitz, 1989). An intelligent interface is a closed-loop system that uses feedback to modify system behavior until a goal is realized. Kantowitz (2001) has explained how intelligent interfaces can be applied to manage driver workload by using dynamic allocation of function (Kantowitz & Sorkin, 1987). The simplest workload manager uses a binary strategy whereby specific sub-systems are either on or off. For example, an in-vehicle cell phone could be turned off when driver workload is too high with messages diverted to a mailbox (Piechulla et al, 2003).

But there are far more sophisticated solutions than simple binary filtering based on a red line threshold. If we think of intelligent control of a system as a continuum bounded by complete manual control versus complete automatic control, an optimal intelligent interface could assume any state along this continuum. This optimal interface could control modes and sub-tasks for in-vehicle devices and so transition more gracefully and continuously than a simple binary interface that energizes or disconnects entire telematic devices. For example, data entry for a navigation system could be disabled while the vehicle is in motion while other, less intrusive navigation functions, could be maintained. Kantowitz (2001) has discussed potential difficulties, such as uncertainty about system mode that has caused serious aviation accidents, in sophisticated intelligent interfaces.

The present results imply uses for both kinds of workload manager: binary filter and continuous control. A simple binary filter should be used to limit the number of simultaneous telematic tasks to no more than two. A continuous workload manager would then control the remaining one or two telematic tasks, depending on total driver workload. Telematic task components that require mostly perceptual processing, similar to the visual RT task used in this experiment, would be enabled. Task components that required substantial outputs might be suppressed. Task components that require medium levels of cognitive workload, like rehearsing digits in the present experiment, could be allowed or not based upon total workload.

This continuous approach will require a cognitive task analysis applied to the specific telematic systems being evaluated. Such analyses require a cognitive model, such as the Kantowitz-Knight hybrid model or other computational model that relates telematic task components to workload. Indeed, without a computational model, every new telematic system would require a new empirical evaluation which is hardly practical for the automotive industry. Phase 2 SAVE-IT research could select some actual new telematic devices for cognitive task analyses aimed at predicting driver workload.

6.4.4. Methodological Issues in Establishing Driver Workload

As expected, results (Figure 6.20) confirm that visual RT is a useful index of driver workload with greater latencies for curves relative to tangents, consistent with previous studies (e.g., Kantowitz, 1995). Both detection (Donders A) and identification (Donders B) responses were able to discriminate between Parked single-task control conditions and dual-task conditions. However, when driver workload was greatest, the Donders B reaction was a more sensitive index than the Donders A reaction.

The present experiment used a modified Peripheral Detection Task (PDT) because stimuli were not presented frequently. Prior research on aviation pilot workload distinguished two types of secondary task: asynchronous and synchronous (Kantowitz et al, 1987). An asynchronous secondary task presents free-running stimuli that occur independently of the state of the primary task. The diagnostic value of a single stimulus is low but many stimuli are presented to make up for this deficiency. If the asynchronous secondary task is embedded more frequently than might occur in a naturalistic setting, the task can create an artificial elevation in operator workload. The synchronous task minimizes this risk by presenting far fewer stimuli. These stimuli are linked to critical events in the primary task. Thus, the present procedure where visual RT stimuli were presented when the lead vehicle braked represents a synchronous secondary task.

While steering entropy was a successful indicator of driver workload (Figure 6.19), it suffers from the constraint that it is measured in a large window. While the present study used a 60 sec window, much smaller than using the entire scenario as was done by Nakayama et al (1999), this is still probably too large for a practical in-vehicle workload manager. Furthermore, the inability of this metric to distinguish between no secondary task and one secondary task is disappointing. This may be related to the large size of the calculation window. It would be useful in Phase 2 of SAVE-IT research to investigate the sensitivity of steering entropy to window size with the goal of determining the smallest size window that is an effective estimator.

6.5. REFERENCES

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