

***Development of a Human Performance Simulation
Model to Evaluate In-vehicle Information and
Control Systems in Commercial Trucking
Operations***

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1 BACKGROUND

The level of technology in personal automobiles and commercial vehicles of today has notably increased to include devices such as cell phones, navigation systems, or other in-vehicle information systems. With this increase in technology, concern over whether the tools provided to drivers do more harm than good has also increased. As higher percentages of the population are exposed to these in-vehicle technologies, regulatory agencies, company management, and researchers have become concerned that activities which compete with the primary task of driving will cause drivers to become more distracted. Distraction can simply cause drivers to commit more driving errors (lane departures) but also has been a factor in over half of the traffic accidents caused by inattention (Stutts, Reinfurt, Staplin, and Rodgman, 2001).

One of the most pervasive in-vehicle distractions is the use of cell phones (Hanowski, Kantowitz, and Tijerina, 1995, Cave, 2005, McCartt et al, 2005, and Schreiner, 2006). Additional distractions include conversations with vehicle passengers (Recarte and Nunes, 2003), general in-vehicle tasks such as tuning the radio and adjusting the climate controls (Tijerina, Kiger, Rockwell, Tomow, Kinatader, and Kokkotos, 1995), and tasks involving an in-vehicle navigation or communication system with visual and manual components (Hanowski, Kantowitz, and Tijerina, 1995, Blanco, 1999, Gellatly and Kleiss, 2000, and Hankey, Dingus, Hanowski, Wierwille, Andrews, 2000b, and Harbluk, Burns, Go, and Morton, 2006). In response to these distractions, some states have passed laws banning behaviors that might distract from driving. Most notably, based on safety concerns, 22 states and Washington, DC have limited the use of cell phones while driving by either requiring the use of a hands-free device or banning cell phone use entirely (Cave, 2005).

While distracting tasks in the vehicle may decrease safety, a number of active safety devices (adaptive cruise control, lane departure, and collision avoidance) have been developed to increase vehicle safety. To demonstrate this increase in vehicle safety, one study combined an in-vehicle information system with two methods of warning drivers; an advising strategy would alert drivers of potential dangers (lead vehicle braking or curve entry) or a locking strategy would prevent further interaction with the information system during these danger periods (Donmez, Boyle, and Lee, 2006). Both of these adaptive interfaces were shown to decrease abrupt braking and improve the breaking response for distracted drivers.

Adaptive cruise control (ACC), one of the active safety devices developed to alert drivers of potential dangers, may decrease the chance of driving errors due to distraction. While the ACC system does control speed like a traditional cruise control system, it also controls the following distance to the lead vehicle. Such a system may effectively counteract inattention to the tasks of speed and maintaining appropriate following distance, which may occur as drivers perform in-vehicle tasks. ACC systems generally implement laser radar to track the lead vehicle and decrease the acceleration of the driver's vehicle if necessary. The

system is adaptive, as opposed to automatic, in that it requires input from the driver. For example, one test system required the driver's input if more than gentle braking was required (Tanaka, Ishida, Kawagoe, and Kondo, 2000).

In addition to ACC, lane departure devices have begun to emerge in many driver assistance systems. A lane departure device uses an image processing unit and cameras mounted on both sides of the vehicle to track the dividing lines on the road and alert the driver if the vehicle accelerates too quickly toward either line. Too great of an acceleration toward either side of the road could represent an unintended lane departure and therefore could cause an accident if the lane departure system did not signal the driver of the impending departure. Signals of departure in such a system can range from an auditory warning (a buzzer noise) to a visual warning (a blinking light) or a haptic warning (seat vibration).

A collision avoidance system implements a similar set of equipment to warn drivers of potential collisions if other vehicles are detected beside the driver. The system would be activated if the driver accelerated toward a different lane or signaled to change lanes and the system's cameras detected another vehicle in the driver's desired lane. As with the lane departure system, various collision avoidance systems implement different warning signals. The three active safety devices discussed may also be used in combination with one another. For example, a driver may choose to use adaptive cruise control, a lane departure device, and a collision avoidance system during a long highway drive which requires very few speed alterations or lane changes.

There are a number of advantages and disadvantages to using these active safety devices. The primary advantage to all three of the devices is their potential to increase driving safety. However, such systems may also create a sense of dependence and thereby delay the driver's operating response. Additionally, the signals generated by the systems may be confusing and may not initiate the appropriate driving response. As with many anticipatory systems, these active safety devices may also have a tendency to generate nuisance warnings, or false alarms, especially if not integrated properly. Above all, the systems must not be used as a crutch for the driver but rather assist the driver when they are needed.

The workload demands on the driver affect both the pleasure and safety of the driving experience. The driver's primary task is comprised of lanekeeping and obstacle avoidance. In addition to this primary task, many distractions such as the driver's cell phone, radio, or navigation system demand the driver's attention. Finally, active safety devices such as adaptive cruise control, lane departure, and collision avoidance systems strive to make the driving experience safer by either warning the driver of danger or actually controlling the vehicle for the driver. The objective of this research is to validate a computer simulated workload model, used to evaluate the effects of each of these components of the driving task.

2 LITERATURE REVIEW

Mental workload has been defined as “an intervening variable, similar to attention, that modulates the tuning between the demands of the environment and the capacity of the organism” (Kantowitz, 2000). Workload can be viewed as a pool of resources that has a limited capacity based on an individual’s skill, knowledge, and abilities. These resources can be dedicated to one primary task (lanekeeping) or partially diverted to secondary tasks (navigation), with the result that the resource pool for the primary task is less than full (Wierwille, Tijerina, Kiger, Rockwell, Lauber, and Bittner Jr., 1996). If the total demands individuals are greater than their capacity, the required workload will be higher than the resource pool available (Blanco, 1999). When these demands on an individual are above the threshold value, degraded performance can occur. This degraded performance is one of the many ways workload can be inferred. With this concept of limited workload capabilities, models have been developed to predict and evaluate the workload of commercial and personal vehicle drivers. The models focus on both the primary and secondary tasks of the individual as well as the total task demands based on a limited workload capacity.

2.1 Workload Models for a Driving Task

Modeling finite resources ultimately began in 1958 with Donald E. Broadbent’s introduction of the concept of limited channel capacity. Broadbent theorized that stimuli entering the human mind briefly undergo analysis by a selective filter before the individual is conscious of these stimuli. The few stimuli (or one message) selected to pass through the filter, based on physical characteristics, are only then processed in the conscious mind. Broadbent’s theory that only a limited amount of information can enter the mind at a time, much like the bottleneck of a system, has formed a basis for many other limited resource models. Several of the models that relate the limited resource capacity to workload during driving tasks have been developed empirically, based on data collected in operational environments, while others have been based on human information processing theory. The following models are examples of those models developed in the areas of commercial vehicle operations and standard vehicle use.

In their 1992 report, Wierwille, Tijerina, Kiger, Rockwell, Lauber, and Bittner Jr. (1992) named the resources of visual, manual, cognitive, auditory, and speech, as the basic channels through which humans perform. In further work on this report, Tijerina, Kiger, Rockwell, and Wierwille (1995) conducted an assessment of the workloads of truck drivers performing twelve in-cab tasks in order to produce an evaluation of the device associated with those tasks. The tasks implemented were right mirror detection and discrimination, left mirror detection and discrimination, changing CB volume or frequency, tuning the radio, changing the radio volume, reading the clock and air pressure, changing the climate controls, and calculating the

available driving hours. The measures used to obtain workloads fell into the categories of visual allocation, driver steering, pedal, and manual activity, driver-vehicle performance, and driver subjective assessments, which combined to form an overall evaluation of the new device.

In performing the evaluation of the drivers' visual allocation, the experimenters calibrated drivers' head and eye positions by asking them to look at specific locations and then recording their head and eye positions on videotape to be used as a reference in later analysis. After data collection, road type (two-lane rural road versus urban or rural freeway) was found to have a significant effect on visual demand, lighting type (day or night) had a smaller significant effect on demand, and the total device glance times were found to vary from 0.90 to 6.75 seconds, representing the total time drivers spent looking away from the forward scene to complete a task. In this case, the longer the total time spent looking away from the scene, the higher the attentional demand of the task.

The driver activity measures used consisted of variance in steering velocity, variance in accelerator pedal position and velocity, counts of accelerator holds and releases, and number of brake applications. The two-lane rural road was found to have the greatest accelerator and brake activity, followed by the urban freeway and the rural freeway. Lighting did not have an effect on steering, but it did significantly affect the accelerator and brake measures. In terms of secondary tasks, those tasks which took the longest (tune radio and tune CB) were associated with the largest change in the most steering measures (Tijerina, Kiger, Rockwell, and Wierwille, 1995).

The IVIS (In-Vehicle Information System) DEMAnD (Design Evaluation and Model of Attention Demand) program developed by Monk, Moyer, Hankey, Dingus, Hanowski, and Wierwille in 2000 was built after an extensive review of driver attention literature. Actual designers of IVIS technologies were asked to consult with the program developers to create a realistic program which could be installed and run in a Windows operating environment and which was the result of the analysis of data gathered in four experiments performed exclusively for the program's development. Two goals in developing the program were to provide designers of IVIS technologies with guidelines to evaluate the attentional resources required by IVIS designs and to provide highway planners and engineers with guidelines to evaluate proposed IVIS requirements. The program modeled driver's resource levels and provided baseline values at which drivers would be affected or substantially affected (Monk, Moyer, Hankey, Dingus, Hanowski, and Wierwille, 2000). For example, in terms of time, if a single glance lasted 1.6 seconds or longer, it was said to affect driving performance; single glances lasting 2.0 seconds or longer were said to substantially affect driving performance. Similarly, driving performance would be affected if the number of glances to the IVIS system was 6 or more, and driving performance would be substantially affected if the number of glances was 10 or more.

The original Multiple Resource Model developed by Wickens and Yei (1986) was intended to predict drivers' performance and allow interpretation of subjective assessments of the drivers' performance. Wickens and Yei divided the processing resources that allow

human performance along three dimensions: processing modalities, processing codes, and processing stages. The processing modalities were the manipulation of visual or auditory display material or the voice or manual responses of the subject. Processing codes were mental operations on spatial or verbal material, and the two processing stages were operations in perception and memory and response operations.

The Multiple Resource model was subsequently expanded to include interference among resource modalities (Horrey and Wickens, 2003). Interference among modalities, however, has never been effectively modeled. Horrey and Wickens' model (2003) strived to become a tool for predicting the impact of different in-vehicle technologies on driver performance. The workload calculations were based on varying levels of finite, separate resources. The resources were divided into perceptual, cognitive, and response resources and were all limited in capacity. Similar to Wickens' early model, the perceptual resources were visual (focal and ambient) and auditory (spatial and verbal), the cognitive resources were spatial and verbal, and the response resources were spatial and verbal.

A matrix, called a demand vector, showed the level of each resource used for a specific task. Each task was coded on an ordinal scale with 0 indicating that the task did not require a particular resource and 1 indicating that some resources were demanded. The demand level could increase to 2 or 3 or above, depending on the amount of resources required by a task. In addition to the demand vector, a conflict matrix was developed to show how resource competition increased with task difficulty. One task was placed across the top of the conflict matrix and one was placed down the left side. The conflict matrix contained values ranging from 0 to 1, with 0 indicating that the two tasks did not interact for a particular resource and 1 indicating that the maximum amount of interaction occurred for a resource. The model produced a total interference score, used to represent an interference level relative to other task combinations. The validation of this model revealed that the model was relatively robust and flexible in application. Although it did not correctly predict lanekeeping variability, the model accurately predicted the performance indicators of task response time and hazard response time during the driving task (Horrey and Wickens, 2003).

2.2 Examples of Resource Allocation

In the context of these limited resource models, this study entertains the visual, auditory, cognitive, and response resource modalities. These modalities are derived from those named by Horrey and Wickens in the Multiple Resource Model (2003).

2.2.1 Visual

Because the majority of the information a driver uses for the primary task of driving is visual, visual resources have been carefully analyzed for their contribution to workload

calculations (Wierwille, Tijerina, Kiger, Rockwell, Lauber, and Bittner Jr., 1996). The two visual resources the Multiple Resource Model calls focal and ambient are referred to by Wierwille et al. as foveal and peripheral visual resources. The focal visual resource corresponds to those images on which the driver fixates onto the fovea of the eye and provides high resolution capabilities which allow the driver to collect detailed information about his environment. This resource is often measured in terms of the glance time at an object or the average number of glances to an object (Hankey, Dingus, Hanowski, and Wierwille, 2000a). For example, drivers might use focal vision when reading a street sign or the caller identification on their cell phones. In contrast, ambient vision gives the driver only motion or outline impressions of objects but can be useful in detecting potential hazards, especially those in motion relative to the driver (Wierwille, Tijerina, Kiger, Rockwell, Lauber, and Bittner Jr., 1996). An example of ambient vision would be drivers detecting an animal crossing the road due to the motion sensed in the periphery.

2.2.2 Auditory

Although auditory resources are not essential for driving, evidenced by the fact that many deaf drivers exist, drivers do generally use their sense of hearing to help them drive. The Multiple Resource Model defines two auditory channels: spatial (hearing sounds from one's environment) and verbal (hearing speech). Auditory cues are most often used as warning signals for the driver and signals for in-vehicle communication systems. The auditory channel has also been explored as a major avenue through which secondary tasks may be performed while driving since the visual channel demands may already be high. In support of this claim, Wickens and Seppelt (2002) compared the results of eighteen studies which focused on auditory versus visual information presentation and found that the majority of the time, auditory presentation resulted in better driver performance than visual presentation on both head-up and head-down displays. However, the decision to use the auditory channel for secondary tasks can be effected by drivers' ages. Older (65-80) drivers have been found to comprehend auditory messages as well as younger (18-22) drivers; still, some evidence exists that auditory cues with various meanings are too difficult for older drivers to memorize, one argument against the use of auditory cues (Kantowitz, Hanowski, and Garness, 1999).

2.2.3 Cognitive

In addition to the visual and auditory components of driving, a cognitive component is associated with the primary task of driving and with secondary tasks. The magnitude of the cognitive resources used by drivers can vary tremendously with the driving situation. If the driving task is simple and no secondary task is required, the cognitive resources (mental attention) required will be significantly fewer than if the driving task is difficult and paired with

a difficult secondary task. The Multiple Resource Model divides the cognitive resources into two sets: cognitive spatial and cognitive verbal resources. Cognitive spatial resources are dedicated to mental tasks concerning objects or ideas in the driver's environment, while cognitive verbal resources are used to analyze and comprehend text or speech. In a study focused on whether or not in-vehicle information systems decrease driving safety, Blanco (1999) stated that the amount of attention resources is finite, therefore in-vehicle information systems could potentially degrade driving safety by requiring more cognitive resources than are available. Others have made the argument that fewer cognitive resources are available for good decision-making when the cognitive demand of a situation is high (for example in highly dense traffic) than when the situation has a low cognitive demand (Baldwin and Coyne, 2003). Because cognitive loads are difficult to measure, workload estimations, such as processing decrements, are generally used to represent the level of the cognitive load.

2.2.4 Response

The Multiple Resource Model also describes the response resource and divides it into two parts: response spatial resources and response verbal resources. Response spatial resources are what Wierwille, Tijerina, Kiger, Rockwell, Lauber, and Bittner Jr. (1996) referred to as manual resources and what were visually monitored by Hankey, Dingus, Hanowski, and Wierwille (2000a) using drivers' hand position. Response spatial resources are used in any task that requires the driver to control the system with his or her hands or feet. Therefore, the required response spatial resources when driving on a straight road with no traffic and no distraction tasks (the driver can use one hand) would be significantly lower than the response spatial resource required while performing a manual task on a highly curved road with oncoming traffic, which might require the use of two hands. Unlike response spatial resources, response verbal resources cannot be visually monitored; they are completely auditory and are used when the driver must speak. The primary task of driving does not usually call for these response verbal resources; however, many secondary in-vehicle tasks are beginning to require verbal response.

2.3 Driving Tasks

Mental workload values obtained during the primary task of driving have been used to create baseline levels to which other incremental workloads are added. These incremental workloads are generated by the driving situation, which includes road characteristics, the presence of other vehicles, and in-vehicle tasks.

2.3.1 Primary Driving Tasks

The primary task of driving consists of both lanekeeping and obstacle avoidance. Lanekeeping refers to controlling the vehicle within the boundaries of the driving lane, while obstacle avoidance in driving refers to avoiding vehicles, pedestrians, or other items on the road. Changes in this primary task can cause significantly different mental workloads. The driver's lanekeeping task may vary due to required changes in speed and changing road curvatures, and the driver's obstacle avoidance task may become substantially more difficult with the presence of additional vehicles or objects on the road.

In one study which calculated mental workload, demand was measured as a percentage of time drivers chose to focus their attention on the forward scene (Mourant and Ge, 1997). This percentage was calculated by allowing subjects to control how much time they spent viewing the roadway with a foot switch, with specific instructions to view the forward scene as little as possible. These attentional demand measurements increased significantly (9 percent) as vehicle speed increased from 33 kilometers per hour to 100 kilometers per hour. The finding that attentional demand only increased by 9 percent (77 to 86 percent) was explained by stating that the primary task of driving can require substantial amounts of attention, even at lower speeds.

Mourant and Ge also considered the differences in the attentional demands of drivers on curved and straight portions of roadway. Again, the difference was significant; the attentional demand of drivers on curves (85 percent) was significantly higher than the demand of drivers on straight roads (81 percent). The severity of the curve also had effects on the drivers' attentional demands. On less severe curves, the demand was lower (83 percent) than the demand on more severe curves (89 percent). Interestingly, traffic was shown to significantly affect the level of attentional demand only on the curved portions of roadway. While driving on curves, the demand of moderate traffic (88 percent) was greater than the demand with no oncoming traffic (80 percent). Mourant and Ge (1997) highlighted the differences in demand caused simply by changes in the primary driving task. Attentional demand was found to vary significantly with all three components of their drivers' task: speed, curvature, and traffic density.

2.3.2 Secondary or Distraction Tasks

In addition to the workload demands experienced during the primary task of driving, workload models can be used to relate driver workload levels to performance during various secondary tasks. Concern over whether in-vehicle information systems and other technology help or actually hurt the driver by requiring secondary tasks, which compete with the primary task of driving, has led to debate. Distraction tasks used in the past to analyze this debate have included standard commercial vehicle operator (CVO) tasks, cell phone or radio tasks, and visual, auditory, or manual in-vehicle navigation system tasks. Typical tasks that have

been used in CVO studies include looking at side mirrors, manually tuning the radio or adjusting its volume, adjusting CB volume or frequency, reading the clock and air pressure, adjusting the heating or air conditioning, and calculating available driving hours (Tijerina, Kiger, Rockwell, and Wierwille, 1995). Many times truck drivers may have different skills and driving experience than the average passenger car driver and therefore make fewer or no errors while performing in-vehicle tasks (Tijerina, Kiger, Rockwell, Tomow, Kinateder, and Kokkotos, 1995). This suggests that advanced technology, such as text message systems, voice communications systems, or route guidance systems, may be more safely introduced into a commercial vehicle fleet than into normal passenger cars.

A study also performed in 1995 focused on cell phone use by truck drivers. During conversations in which subjects listened and responded to messages on a cellular telephone, drivers accumulated a greater number of lane exceedences, a measure of workload, than during driving alone (Hanowski, Kantowitz, and Tijerina, 1995). In another study, drivers listening and responding to verbal messages significantly underestimated the importance of the road conditions while distracted by the messages (Cooper and Zheng, 2002). A mathematical equation was used to determine whether the risk of potential collision was high or low for drivers choosing whether or not to turn left onto a test track full of other vehicles. On wet pavement, drivers who were distracted by the verbal messages accepted high-risk gaps in traffic twice as often as drivers who were not distracted. Cooper and Zheng (2002) concluded that the distracting verbal messages, which could be likened to cell phone conversations, reduced the drivers' ability to process all the information necessary for safe decision-making.

Phone or passenger conversations, not simply incoming verbal messages, can cause this lack of decision-making ability in drivers (Recarte and Nunes, 2003). Information received while driving was shown to create little distraction when the tone of the information was neutral and required no immediate action. Alternatively, complex conversations delivered higher attentional demands, shown by a change in pupil size, indicating additional mental effort. These increased demands on the driver's attention can lead to decreases in detection ability, in some cases by as much as 30 percent, and are "dangerous for road safety" (Recarte and Nunes, 2003). A number of additional studies have examined the effect of cell phone use on drivers' attention (Schreiner, 2006 and Redelmeier and Tibshirani, 1997).

With respect to other tasks performed in vehicles, such as text messaging and navigation, several measures of distraction have been utilized. Text messages presented to drivers on CRT displays in a 1995 study were found to cause an increase in the drivers' lanekeeping variability, a statistic derived from the output variable "standard deviation of vehicle lane position error" in the experiment's STISIM simulator (Hanowski, Kantowitz, and Tijerina, 1995). This increased lanekeeping variability could be viewed as a negative addition to road safety and an indicator of distraction. Additionally, when performing conventional tasks such as adjusting the radio or climate controls or making a cell phone call, drivers took less time to perform these tasks using the conventional system (radio, climate control, or cell phone) than using a prototype multifunction information system containing all these devices in

one unit. However, Gellatly and Kleiss (2000) noted that some tasks created specifically for the multifunction information system (navigation/communication) were completed more quickly than any of the conventional tasks. Therefore performance might drastically improve with drivers who had time to adjust to the new information system.

The Society of Automotive Engineers (SAE) addressed the issue of distraction with the publication of SAE Recommended Practice J2364, also known as the 15-Second Rule for Total Task Time. SAE Recommended Practice J2364 presents guidelines for acceptable navigation system tasks (Society of Automotive Engineers, 2000). According to this rule originally written by Paul Green (1999), tasks performed using a navigation system with manual controls and visual displays should have a total static (vehicle not in motion) task time of 15 seconds or less. The 15 second limit was selected by a subcommittee of experts who concluded that “a longer static task time could unduly degrade safety” and that most tasks currently performed in automobiles (radio tuning, HVAC adjusting) take fewer than 15 seconds to complete. Green (2000b) later discussed potential expansion of the rule to model other driving task situations. During validation studies for the rule, the average eyes-off-the-road time was between 60 and 75 percent of the total task time, or approximately 10 seconds. From this observation, Green hypothesized that the rule may expand to apply to other tasks with manual or visual components. For example, for solely visual tasks such as reading road signs, the rule could potentially limit the static task time to the 10 seconds observed during the validation studies.

Another set of rules or guidelines concerning the presentation of in-vehicle information system (IVIS) tasks to commercial vehicle operators was derived from an on-the-road experiment which measured eye glances, longitudinal and lateral driving performance, secondary (or distraction) task performance, and subjective assessment from the truck drivers (Blanco, 1999). The eye glance data was recorded on videotape and then analyzed for five eye glance measures: number of glances to the IVIS display, number of glances to the mirrors, longest glance to the display, average single glance time, and total glance time. Longitudinal performance measures consisted of the minimum speed driven, the decrease in speed, the average speed, and the standard deviation and variance of the speed. Longitudinal deceleration was also measured using an accelerometer. Regarding lateral driving performance, the researchers counted the number of lane deviations (any wheels of the vehicle going over the outside edge of lane markers on either side), the peak, average, and variance of the steering wheel velocity, and the vehicle's peak lateral acceleration.

For the secondary task portion of the experiment, time to complete the task was calculated, along with the number of drivers who skipped a task, answered a question incorrectly, or performed the wrong task. The drivers were asked to assess their own mental workloads using a modified version of the NASA-TLX (Task Load index) (Hart and Staveland, 1988) assessment (discussed in further detail later in this document) and were also asked to provide a subjective measure of their situational awareness.

The guidelines formed from these measures stated that in-vehicle information systems should not present information in paragraph format while the vehicle is in motion, that

graphics with icons are the most appropriate form of presenting information, that the driver should only perform simple search tasks to find information, and that only the most important route information should be presented (Blanco, 1999). Many believe that presenting auditory in-vehicle tasks instead of visual ones can produce safer systems because auditory tasks do not interfere with the primarily visual task of driving. However, even tasks presented completely in the auditory mode represent cognitive loads. These increases in cognitive workload can negatively impact driving performance. Drivers may commit more errors on the navigation tasks or disregard visual information in order to process the auditory information, thereby missing key clues in the driving scene.

2.4 Measurement

The methods used to determine driver workload can be divided into three categories: physiological indices, task performance parameters, and self-reports of mental workload (De Waard, 1996). Among the physiological indices are eye movements and heart rate variability, and among the task performance parameters are lane position, steering and speed, response times, and task errors. Self-reports of mental workload are obtained through any of a number of subjective assessments, which have been compared for their diagnostic capabilities. These methods of measuring driver workload can be collected in experiments performed using driving simulators or in on-road driving experiments.

2.4.1 Research Environment

A large volume of literature exists on the advantages and disadvantages of performing driving studies in a driving simulator. One on-road study has suggested that drivers become more relaxed during simulator driving versus on-road driving and thus accumulate more errors in the simulator and that the visual, kinesthetic, and auditory cues available on the road are diminished in the simulator (Hanowski, Kantowitz, and Tijerina, 1995). Another discovered that testing the effects of wet and dry road conditions could not be accurately performed in simulation (Cooper and Zheng, 2002). Recarte and Nunes (2003) also argued that a high processing density, not always a feasible one, is required in most laboratory experiments to achieve a realistic scenario.

While arguments against the use of simulation exist, many practical and safety considerations outweigh these arguments. If certain measures of workload (such as reaction time to sudden lead vehicle braking) cannot be systematically captured in the field, simulators provide convenient solutions. Also, road curvature and driving scenario conditions may not be as readily manipulated in the field as they are in the use of a simulator (Hanowski, Kantowitz, and Tijerina, 1995). Obviously, if the safety of the driver is in jeopardy in a study, simulation provides a safe alternative to field tests; one study which sought to increase the workload

imposed on its participants incrementally, measured by an increase in the number of errors or the time it took subjects to react to certain events, would not have been safely implemented in the field and was therefore performed in a driving simulator (Merat, 2003). The financial implications of using a driving simulator as opposed to an instrumented test vehicle must be considered, but most importantly, the use of a driving simulator may allow researchers to more easily collect data pertaining to the following workload measures.

2.4.2 Eye Movement and Other Physiological Measures

Because drivers use vision as a major means of evaluating their environment, eye movement analysis has often been used to capture the drivers' area of visual attention at all points during an experiment. Visual allocation, the area to which the driver is visually attending, refers to those things looked at with focal as opposed to peripheral vision. Eye movement measures are believed to be the most important means of assessing workload associated with an in-vehicle task, and therefore the task's safety (Tijerina, Kiger, Rockwell, and Wierwille, 1995). Eye movement analysis can be used to determine areas experimenters should emphasize when presenting experimental results. Based on manually analyzed images of drivers on two-lane rural roads and those driving on rural or urban freeways, drivers on two-lane rural roads spent significantly less time looking away from the road than drivers following rural or urban freeways (Tijerina, Kiger, Rockwell, Tomow, Kinatader, and Kokkotos, 1995). This could be due to the divided nature of the highways as compared to the more intense lanekeeping needs of drivers on two-lane roads. The researchers concluded that the workload measurements taken in a study are not complete without an accurate description of the road the drivers are required to navigate.

Ocular behavior analysis has also been used to evaluate the cognitive workload imposed on drivers during various mental tasks. By recording drivers' pupil size, experimenters could determine effort due to additional mental loads. The analysis of visual search patterns and the frequency of mirror and speedometer glances also enabled a measure of awareness during driving. With the addition of mental tasks, drivers' pupil size increased, indicating increased mental effort, and the number of detected targets decreased. Although the number of mirror and speedometer glances also decreased, showing a decreased situational awareness, this reduction could also be due to the driver effectively balancing their visual resources (Recarte and Nunes, 2003). Aside from glance frequencies, blink frequencies have been used as a means for identifying more highly visually demanding tasks in the study of pilot workload (Wilson, 2001). Additionally, multiple studies in recent years have used glance behavior as an indicator of mental workload and risk recognition (Thompson, Toennis, and Lange, 2006 and Pradhan, Fisher, Pollatsek, Knodler, and Langone, 2006) and others have focused on the use of peripheral vision decrements in identifying peaks in workload (Martens and van Winsum, 1999).

While eye movement analysis has been used to form baseline values for the durations drivers spend looking on and off the road as well as at mirrors and the instrument panel, specific eye movements can be used to analyze where the driver's cognitive focus, not just his visual attention, lies. A future active safety system could be developed by analyzing these specific eye movements and would intelligently predict the driver's next action based on his eye movements to possibly reduce the risk of accidents. Factors which may interfere with such precise eye movement analysis include nighttime driving, rainy or foggy weather, or driving with glare on the road. One drawback to using eye movement data to develop such a system is that individual differences may be so large that a system cannot generalize eye movements into predictions about what the driver will do (Liu, 1998).

In the context of piloting, a task which shares characteristics with the driving task, physiological measures have been used to determine mental workload. One such study used heart rate and heart rate variability to determine the pilot's level of mental workload (Wilson, 2001), and at least one has found that the measurement of sympathetic and parasympathetic heart beat components can provide increased precision for mental workload evaluation (Bucks, 1995). Takae, Etori, Watanabe, Kubo, Yoshitsugu, and Miyake (2005) also considered blood vessel constriction as a physiological measure of workload in the context of drivers performing complex mental route-planning tasks. Finally, De Waard (1996) suggested the use of respiratory, electrodermal, and hormone level measures as indicators of workload in drivers.

2.4.3 Lanekeeping, Steering, and Speed

The normalized number of lane departures, mean lane position, and peak lane exceedence distance are examples of lanekeeping or steering measures of workload. De Waard (1996) suggested the use of these measures not only during secondary tasks, but during reference tasks, or those tasks performed before and after the task under evaluation, to obtain a baseline for each of the measurements. When driving, cognitive attention focused on vehicle tasks may distract the driver from appropriately tracking the road. Mean lane position data collected for truck drivers performing various tasks indicated that drivers kept closest to the centerline during driving alone, while reading four lines of text, and while tuning the radio, as compared to CRT text message reading. Additionally, drivers strayed significantly from the centerline when asked to answer questions about themselves or to perform arithmetic as compared to driving alone. In terms of lane exceedences, drivers reading in-cab CRT text messages accumulated a greater number of lane exceedences than driving alone (Hanowski, Kantowitz, and Tijerina, 1995).

Alternatively, in a 2000 study, the number of lane exceedences did not increase as drivers took longer to operate in-vehicle information systems (Gellatly and Kleiss, 2000). However, a correlation was found between task completion times and lateral vehicle control. Surprisingly, as the time to complete a task increased, using both conventional vehicle

systems and multifunction information systems (as defined previously), the drivers more aggressively corrected their lane deviations. These aggressive corrections were measured by changes in the vehicle's lateral acceleration. Although more aggressive corrections may be counterintuitive (one would expect fewer corrections as task time increased), they may have been due to the drivers' awareness of being watched by the experimenter.

Lanekeeping measures of driver performance are relevant due to their direct relationship with highway traffic accidents. In order to accurately assess the safety of an in-vehicle task, lanekeeping measures should be included in workload assessments (Tijerina, Kiger, Rockwell, and Wierwille, 1995). Two-lane rural roads have been found to be associated with the highest number of lane exceedences and position variance, most probably due to the demanding nature of lane tracking on such roads. Additionally, long tasks performed on any road lead to increased position variance within the lane.

Speed variations, a measure of driving task performance, can also indicate higher levels of driving workload. As the driver's mental workload increases, the vehicle speed becomes less constant than when speed and lanekeeping are the driver's primary foci. Accordingly, in the same experiment, the variation in drivers' forward speeds linearly increased ($R^2 = 0.76$) with an increase in task completion time (Gellatly and Kleiss, 2000). The speed standard deviation, computed from the longitudinal acceleration recorded by the vehicle, similarly increased when drivers performed in-cab tasks such as radio tuning, reading four lines of text, and dialing local phone numbers (Hanowski, Kantowitz, and Tijerina, 1995). Not only speed variation, but also speed decreases can be signifiers of increased mental workload. In the same experiment, when compared to speeds when simply driving, drivers were found to significantly reduce their speed when performing in-cab tasks, such as reading the in-cab clock, reading four lines of text, and dialing a local phone number.

2.4.4 Response Times and Task Errors

Response time, or the time for the driver to complete a task, has been used as a primary measure of indication for increased cognitive workload. Drivers who were distracted by listening or responding to verbal messages inaccurately chose to accept unsafe gaps in a test traffic stream. This response time lapse was found to stem from the reduced processing capacity of the subjects during the auditory messages (Cooper and Zheng, 2002). Similarly, when compared to drivers performing no secondary tasks, drivers performing mental tasks were shown to take significantly longer to notice a driving target and significantly less time to decide whether or not the target was important (Recarte and Nunes, 2003). Taking less time to determine a target's importance suggests a hasty decision-making process for drivers performing other tasks.

There appears to be a negative linear relationship between drivers' response times and successful driving. Not only do longer response times indicate increased mental workload, but each additional second drivers take to respond to a task corresponds to an

incremental negative impact on driving (Gellatly and Kleiss, 2000). This linear relationship between task completion time and driving holds for conventional in-vehicle systems and advanced information systems alike, and leads to a goal of simplifying in-vehicle tasks in order to minimize driver reaction time.

Similar conclusions about subjects' levels of cognitive workload can be drawn from incorrect responses to tasks as can be drawn from their response times. While listening and responding to auditory messages, subjects' selections of safe traffic gaps were not as accurate as when they were not performing these tasks (Cooper and Zheng, 2002). Drivers executing other mental tasks detected significantly (13 percent) fewer targets (Recarte and Nunes, 2003). Much like increases in response times, task decrements (described by Cooper and Zheng, 2002, as increases in the level of potential collisions initiated when distracted) are believed to begin with increases in mental workload. Records of task errors have been also used to determine the safest location of in-vehicle information displays. Based on drivers' performance on secondary tasks and during their primary task of lanekeeping and braking, the display positions directly above the steering wheel or center console were chosen to have the least detrimental effect on driving performance (Wittmann, Kiss, Gugg, Steffen, Fink, Poppel, and Kamiya, 2006).

However, increased mental workload cannot always be determined by longer response times and task errors. For subjects reacting to a pedestrian crossing the road when performing no secondary task, dialing a cellular phone, or reading a four-line message, no significant changes or decrements were found in the percent of objects detected or in the response time (Hanowski, Kantowitz, and Tijerina, 1995).

2.4.5 Subjective Response

Subjective responses, or questionnaire data from the subject, are often used to provide additional insight into a situation or to supplement other measures if the secondary task and physiological measures at work in a study are inconvenient to obtain. Non-subjective measures can be especially difficult to obtain if a setting is highly operational (Wickens and Yei, 1986 and Wilson, 2001). Because drivers of automobiles are the subjects of study in many situations, the data and insight provided by drivers can be invaluable. A driver may be in excellent position to reveal problems or concerns that arose during the study and his or her impression of the workload experienced during certain tasks (Tijerina, Kiger, Rockwell, and Wierwille, 1995). Because makers of in-vehicle information systems strive to create the safest, most user-friendly system, some checklists have been constructed solely to obtain a subjective value of the driver's mental workload when evaluating the in-vehicle system (Stevens, Board, Allen, and Quimby, 1999). Even scholars in the area of air-traffic control workload have noted that workload estimation should be a combination of measurements and subjective evaluations (Averty, 2004).

One example of a subjective assessment is Hart and Staveland's (1988) NASA-TLX (Task Load index). The NASA-TLX assessment represents globally-sensitive measures of workload by requiring the subject to rate a task according to its mental, physical, and temporal demands and the subject's associated performance, effort, and frustration levels. Scales for mental, physical, and temporal demands and effort and frustration levels have the endpoints of low and high, while good and poor constitute the endpoints for the scale associated with performance. Hart and Staveland found that the rating of task components yielded a more diagnostic measure of workload than the singular, global rating of workload and that each of the six rating areas required different weights in the final model to accurately represent the workload in a given task. NASA-TLX has been found to generate ratings and suggested weights quickly (in approximately 3 minutes after each experimental condition); therefore, it is an especially practical subjective assessment to perform in an operational environment.

Another subjective assessment method is Reid and Nygren's (1988) SWAT (Subjective Workload Assessment Technique). In this technique, workload is defined as being primarily constructed from time load, mental load, and psychological stress load. Subjects performing this technique construct their own workload scale by ranking 27 combinations of the three loads (time, mental, and psychological stress) and three levels (low, medium, and high). Some hesitations researchers may have concerning this technique are the tediousness of developing the scale, the low levels of discrimination offered by only the low, medium, and high categories, and the risk associated with the use of word labels due to their various connotations across subjects (Rubio, Diaz, Martin, and Puente, 2004, Hart and Staveland, 1988, and Blanco, 1999). However, this technique has been suggested to have a greater potential than NASA-TLX in determining cognitive mechanisms affecting workload judgment (Blanco, 1999).

The final subjective assessment technique examined, the Workload Profile (WP) method proposed by Tsang and Velazquez (1996), was compared and contrasted to NASA-TLX and SWAT in a 2004 study by Rubio, Diaz, Martin, and Puente. The methods were compared in terms of their sensitivity, diagnosticity, selectivity/validity, intrusiveness, reliability, implementation requirements, and subject acceptability. The WP method, based on Wickens' Multiple Resource Model, requires the subjects to report the proportion of each attentional resource they used after performing all the required tasks in an experiment. The resources of this model are perceptual/central, response, spatial, verbal, visual, auditory, manual, and speech resources. Although some subjects had difficulty understanding which category corresponded to each part of their perceived demand, the WP method importantly provided a significantly higher level of diagnosticity, or an explanation for the ways in which a task was demanding, than NASA-TLX or SWAT.

2.5 Conclusions

As technology advances and the number of in-vehicle tasks increases, safety concerns associated with driver distractions create a need to more clearly understand these distractions. Accurate measures for determining the workload levels demanded by the distractions have emerged, and models of driver workload during these distractions show great promise in detecting the least safe activities. From the review of the literature concerning driver workload modeling, the model for the current study has been developed. This model, a theoretical one, seeks to provide baseline values for the workloads required during various combinations of tasks and, most importantly, strives to accurately represent the driver's resources at specific points while driving.

3 METHOD

The following section details the assumptions and procedures used in this experiment.

3.1 Definitions

The following operational definitions were used in the development of this experiment.

3.1.1 Mental Workload

Mental workload can be viewed as a pool of resources, which start at a certain capacity due to a subject's skill and knowledge and are either all dedicated to one primary task or are partially diverted to secondary environmental tasks, leaving the less-than-full resource pool for the primary task (Wierwille, 1996).

3.1.2 Visual Focal Resource

The proposed model focuses only on the visual focal resource, rather than also including the visual ambient resource of Horrey and Wickens' Multiple Resource Model (2003). Visual focal resources are perceptual resources used when the driver fixates on images, often repeatedly, to collect detailed information about the environment.

3.1.3 Auditory Focal Resource

Similarly, only the auditory focal resource is defined in this model, replacing the auditory spatial and auditory verbal resources of Horrey and Wickens (2003). The auditory focal resource is defined as a perceptual resource, exercised when the driver attends to sounds or words in the environment. Because this experiment only used sound to warn the driver of an upcoming task, the auditory focal resource remained zero throughout the study.

3.1.4 Haptic Focal Resource

While the Multiple Resource Model of Horrey and Wickens (2003) did not name a haptic resource, the haptic focal resource can be defined as a perceptual resource utilized when the driver feels vehicle vibrations, in-vehicle device controls, or any other part of the environment to obtain information relevant to the driving and distraction tasks. Although this

model did not analyze the haptic focal resource, as active safety devices (lane departure) continue to use vibratory warnings to alert drivers of danger, models containing active safety device variables should also include analysis of the haptic focal resource.

3.1.5 Cognitive Spatial Resource

Cognitive spatial resources are dedicated to mental tasks concerning objects or ideas in the driver's environment.

3.1.6 Cognitive Verbal Resource

Cognitive verbal resources are used to analyze and comprehend text or speech.

3.1.7 Response Spatial Resource

Response spatial resources are used in any task that requires the driver to use his or her hands to provide feedback to the system.

3.1.8 Response Verbal Resource

Response verbal resources are completely auditory and are used when the driver must speak to provide feedback to the system. This experiment did not require the driver to provide a verbal response to complete the tasks; therefore this resource value remained zero throughout the study.

3.2 Demand Model

The following discussion of workload and demand describes the reasoning behind the development of the demand matrix used in this study.

3.2.1 Workload

Workload values for this experiment were divided into three major categories: perceptual demands, cognitive demands, and response demands. The cognitive demand category was further divided into the subcategories of cognitive spatial and cognitive verbal workloads. The experiment also considered the inclusion of auditory focal and response

verbal demands; however, neither of these two workload categories was affected by the tasks used for the experiment, so auditory focal and response verbal workload levels were not further analyzed. All four subcategories of demand were assumed to be independent of each other. Additionally, the four values (one per subcategory) were assumed to be additive in nature, resulting in an estimation of total overall workload. These subcategories are shown in Table 1's column headings below.

Table 1: Workload Category Breakdown

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs

The workload levels of drivers participating in this experiment were predicted to increase and decrease as the driving scenario progressed. Because each workload type was assumed to be independent of all other workload types, one workload level could increase as another potentially decreased for a given task. The values of each of the four demands were based on a scale from 0 to 100, with zero signifying no demand in that category and 100 signifying maximum demand. The value 80 was chosen to mark the point at which decrements in performance were likely to occur.

3.2.2 Demand Matrix

This experiment considered driver workload levels during different driving situations. Workload levels for four road types, three traffic event types, and four navigation event types were estimated and used to develop a demand matrix representing the expected driver workload for any combination of events. Data were then recorded during the driving experiments and used to validate the workload levels estimated by the demand matrix and suggest improvements to the model as a whole. The four road types comprised the lanekeeping portion of the experiment and were straight road, low curvature, medium curvature, and high curvature. All road types were limited to two-lane rural highways.

The traffic avoidance tasks in this experiment concerned the various traffic events to which drivers responded. Throughout the driving scenario, drivers could encounter no other vehicles, a single car meeting event, or a single car overtaking event. See figure 1 for a visual representation of meeting and overtaking.

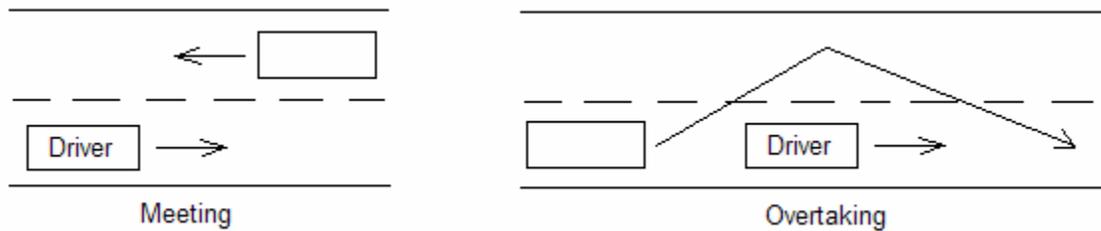


Figure 1: Meeting and Overtaking

Meeting occurred when an oncoming vehicle approached the driver in the opposite lane and the two cars met and passed, while overtaking occurred when another vehicle approached the driver in the driver’s lane from behind, pulled into opposite lane, accelerated and proceeded to move back into the driver’s lane in front of the driver. Passing, an event the driver would initiate, was not considered in this experiment as a traffic avoidance task type. Additionally, multiple car meeting and overtaking were not considered since they were assumed to be multiple sequential occurrences of their single car counterparts.

The navigation events encountered in the scenario were termed distraction tasks. At any point in the driving scenario, a driver could be required to perform no task, a low difficulty task, a medium difficulty task, or a high difficulty task. Performing the tasks required the driver to read a question about a map presented to the driver and give a numeric response via a keypad to the driver’s right.

The lanekeeping task, the traffic avoidance tasks, and the distraction tasks are visually represented in Figure 2 below.

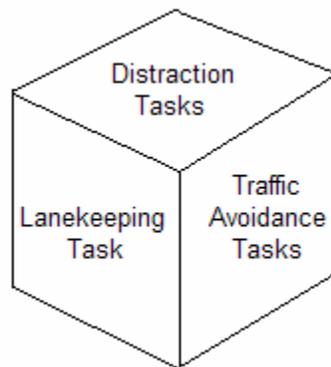


Figure 2: Visual Representation of Three Types of Tasks

The demand matrix was developed for these three types of tasks based on input from a number of individuals. Rows in the demand matrix represented tasks, while columns in the matrix divided the workload values into the four subcategories. Each cell in the matrix represented an independent demand level for that particular task and workload. Table 2 shows the demand matrix, while Appendix A contains the full matrix, including the auditory

focal and response verbal subcategories as well as other tasks not examined in this experiment.

Table 2: The Demand Matrix

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping _Straight	10	15	0	15
Lane Keeping _Curvature_Low	20	20	0	25
Lane Keeping _Curvature_Med	30	25	0	35
Lane Keeping _Curvature_High	40	30	0	45
2_Lane_One_Car_Meeting	25	15	0	15
2_Lane_One_Car_Overtaking	20	20	0	15
Navigation Low Difficulty	15	20	80	25
Navigation Med Difficulty	25	30	80	25
Navigation High Difficulty	30	35	80	25

At any point in the experiment, a workload level could be found by adding the lanekeeping task, traffic avoidance task, and distraction task values for that workload. Therefore, for a driver on a medium curvature road with no other vehicles and performing no navigation task, the workload levels would be found in the single line, Lane_Keeping_Curvature_Med. As reported in the literature review section of this paper, Mourant and Ge (1997) found that the attentional demands of drivers increased by four percent from a straight road to a curved road. As seen in the proposed demand matrix above, the workload levels for medium curvature roads increase as much as 300 percent (visual focal) from the workloads required by a straight road. This difference in increases can be explained by the fact that Mourant and Ge’s study did not require drivers to control their speed during the simulation, whereas the study discussed here did require drivers to attend to their speed.

Another example of the use of the demand matrix to find workload can be seen for the case of a driver on a low curvature road, encountering a single car meeting task, and performing a low difficulty distraction task. For this combination, the visual focal demand would be the sum of 20, 25, and 15 for a total of 60. This value was appropriately higher than the visual focal demand of 10 for driving on a straight road with no other tasks occurring. For the same low curvature road, single car meeting task, and low difficulty distraction task, the cognitive spatial demands would be 55, the cognitive verbal demand would be 80, and the response spatial demand would be 65, as shown in Table 3.

Table 3: Workloads for Low Curve, Single Car Meeting, Low Difficulty Distraction Task

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping_Curvature_Low	20	20	0	25
2_Lane_One_Car_Meeting	25	15	0	15
Navigation Low Difficulty	15	20	80	25
Workload Sums	60	55	80	65

The chance for driver error would be present in this situation because the cognitive verbal demand would reach 80, the threshold for error.

Although the visual demand for a task could be divided into periods of extremely high demand, representing the glances to the navigation screen, and periods of low demand, times when the driver focused only on the road, the values shown in the visual focal column of the matrix can be considered averages of the extreme possible demands at any point during the distraction task. Thus glance times and demand values were taken into account but not specifically addressed in the matrix.

In developing the matrix, interference between two tasks was also considered. Conceptually, interference exists and could occur, for example, while drivers talk and read or listen and read. This interference could be observed as a performance decrement (Horrey, 2003). Although this interference would effectively increase the resources needed to perform these combinations of tasks, most individuals were assumed to avoid this, so the demand matrix was configured in such a way that interference would not be assessed.

3.3 Subjects

Prior to participation in this experiment, subjects completed one of two consent forms approved by the University of Arkansas Institutional Review Board, found in Appendix B. Forty-four students from the University of Arkansas participated, consisting of 34 males and 10 females. Seven drivers were recruited on a voluntary basis and 37, those students in either INEG 3713 Methods and Standards or INEG 4723 Ergonomics, were given credit for their participation. All participants held a valid driver's license and had normal or corrected normal vision. In addition, all were able to hear the auditory cue used to signal the distraction tasks.

The subjects were told that they should notify the experimenter for immediate termination of the experiment if at any time they experienced sensations of motion sickness or dizziness. Subjects also completed a pre-experiment questionnaire, found in Appendix C. This questionnaire was modeled after one in a doctoral dissertation on a similar topic (Stanley, 2006) and gathered information such as age, gender, years of driving experience, and average miles driven per year. The subjects were asked questions regarding simulator sickness tendencies (Seppelt and Wickens, 2003), and their responses were recorded.

Subjects were presented with examples of the tasks they would be performing (Appendix D) and were required to complete a pre-experiment practice scenario, lasting approximately ten minutes, before moving on to the experiment. The instructions to the subjects during the experiment can be found in Appendix E. After the experiment, the subjects answered another brief questionnaire which contained questions pertaining to the external validity of the experiment as well as participant accident history, simulator experience, and participation in a driving education program (see Appendix F).

3.4 Apparatus and Simulation

The following sections provide a discussion of the equipment used in this study as well as a review of the simulation efforts related to the model of demand.

3.4.1 Driving Apparatus

Data were collected in the University of Arkansas' Ergonomics Laboratory. The driving simulation was programmed using the STISIM Drive software (Build 2.03.09, Copyright 1985-2006), developed by Systems Technology, Incorporated of Hawthorne, CA. The driving scenario ran on a Dell Precision Workstation 360 with an Intel Pentium 4, 2.80 GHz processor, and 512 MB of RAM. The 15-inch screen resolution was set to 1024 x 768 pixels, enabling viewing of the system's realistic graphics. Both the speedometer and tachometer on the STISIM screen were 1.5 inches in diameter, and the rearview mirror measured 1.5 inches by 4 inches.

The experiment's steering wheel (13 inches in diameter) and pedals were manufactured by the Grant Company, and the subjects wore Sony Noise Canceling headphones to eliminate any distracting noises in the room. Both the practice and navigation programs used the same program settings, or STISIM configuration. The volume in the subjects' headphones was set consistently to 37.5 on the STISIM configuration scale, and the tire squealing on corners option was turned off. The maximum speed was set to 88 feet per second, or 60 miles per hour.

Figure 3 presents an example of the images presented on the simulator's monitor.

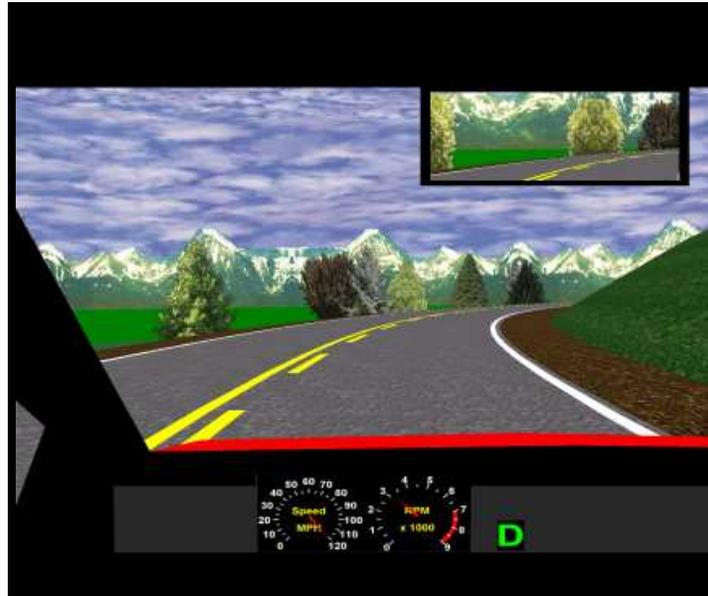


Figure 3: Example Image on Driving Simulator

Participants were seated in a stationary, non-rolling desk chair at a height of 19 inches from the floor to the sitting surface. While seated at the simulator with the hand on the steering wheel, the participant's elbow was bent between 70 and 100 degrees. The table holding the STISIM computer and steering wheel was 25 inches from the floor to the top surface, with an additional 14 inches from the desktop to the bottom of the simulator's screen. Figure 4 depicts this placement.

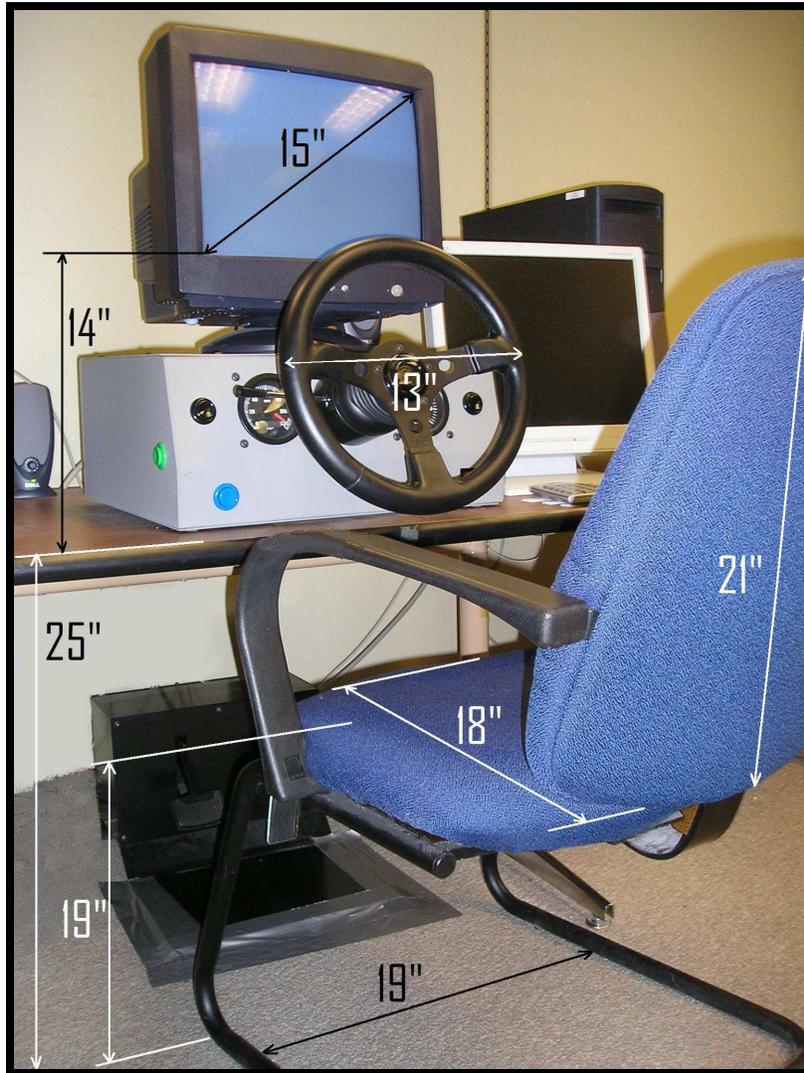


Figure 4: STISIM Computer and Chair Placement

This layout represents a required vertical viewing angle of approximately 22 degrees and a horizontal angle of 25 degrees for the driver to view the STISIM simulation.

3.4.2 Navigation Apparatus

Custom software was developed for the distraction tasks using Visual C++. The program gave the appearance of an in-vehicle navigation system and included simple rural maps taken from DeLorme's Street Atlas USA Deluxe for Windows (Copyright 2001). All maps were edited in Microsoft Paint and were 567 pixels in width and 330 pixels in height. The navigation computer was a Dell Optiplex GX260 with a Windows XP operating system. The 17-inch screen resolution for this system was set to 1024 x 768 pixels for greater map legibility. Figure 5 represents an example task programmed using the software.

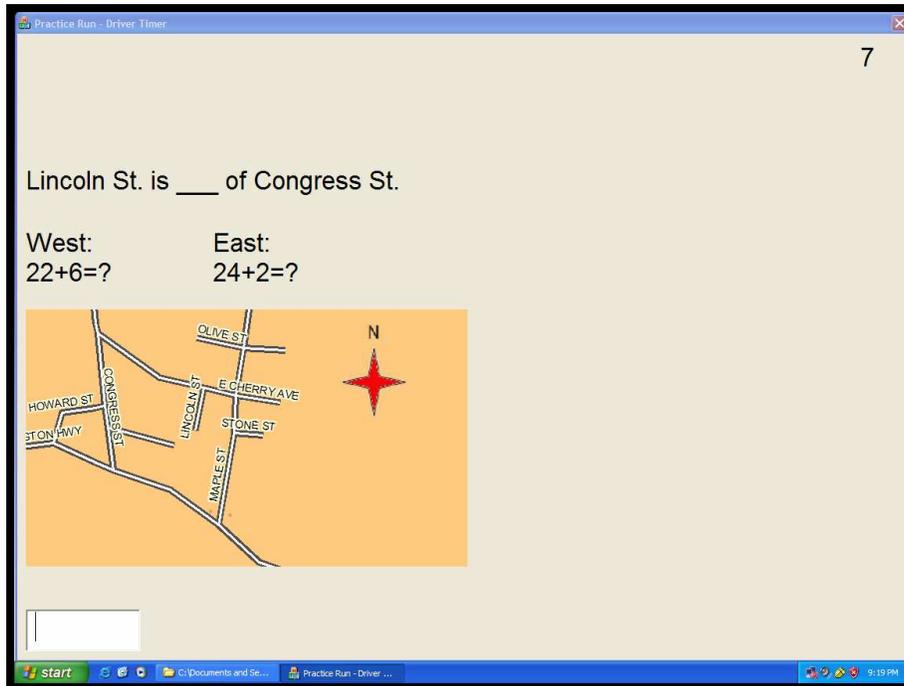


Figure 5: Example Distraction Task Window

Subjects were required to input their answer to the distraction task via a fixed Targus USB numerical keypad to the driver's right. The drivers were asked to keep their right hand on the steering wheel or in their lap until they responded to the map questions so that the hand travel times would be consistently represented in data collection. All of the information on the navigation task monitor was contained in a vertical viewing angle of 20 degrees and a horizontal angle of 18 degrees. In total, an angle of approximately 48 degrees was filled from the leftmost edge of the STISIM monitor to the rightmost edge of the navigation monitor. The total vertical viewing angle was approximately 33 degrees. The following photograph, Figure 6, shows the combined driving and navigation system apparatus.

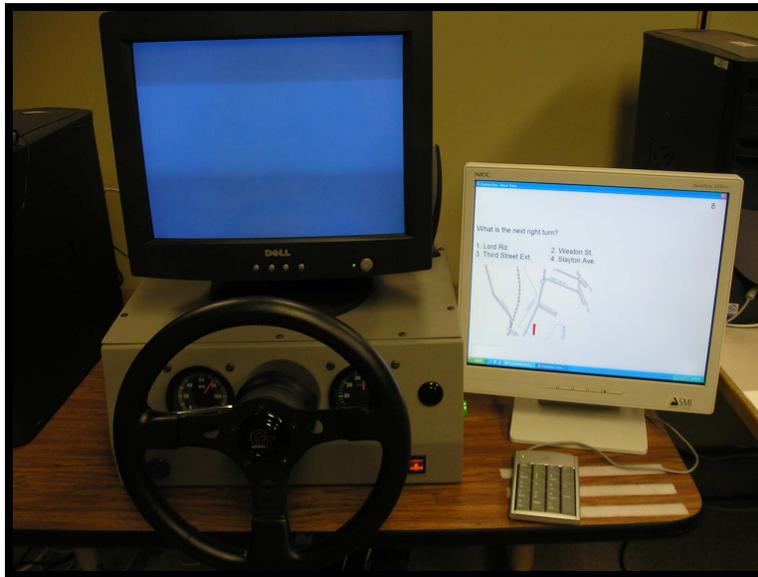


Figure 6: Driving and Navigation Apparatus

To enable ease of data collection, another program was developed which gathered data for each participant from both the STISIM driving program and the custom software and combined the data in a simple Microsoft Excel spreadsheet. Lane position and speed data, recorded on the driving simulation computer, were sent to the database on the navigation computer via a null serial cable and a Measurement Computing digital I/O board (see Figure 7).

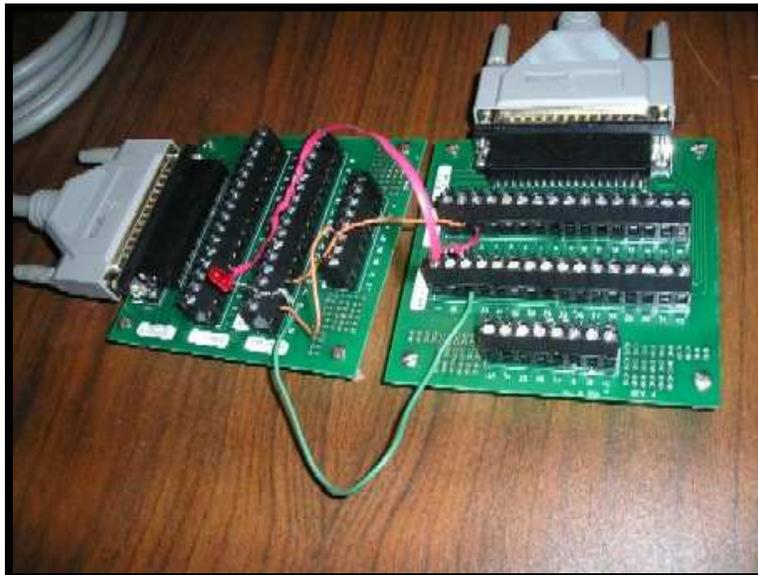


Figure 7: Measurement Computing Digital I/O Board

3.4.3 Workload Simulation

This experiment also considered the use of the MicroSaint SHARP discrete event simulation software in developing a probabilistic model of the car and driver system. The simulation was based on a series of networks; the upper level network can be seen in Figure 8. An example of a sub-network can be found in Figure 9.

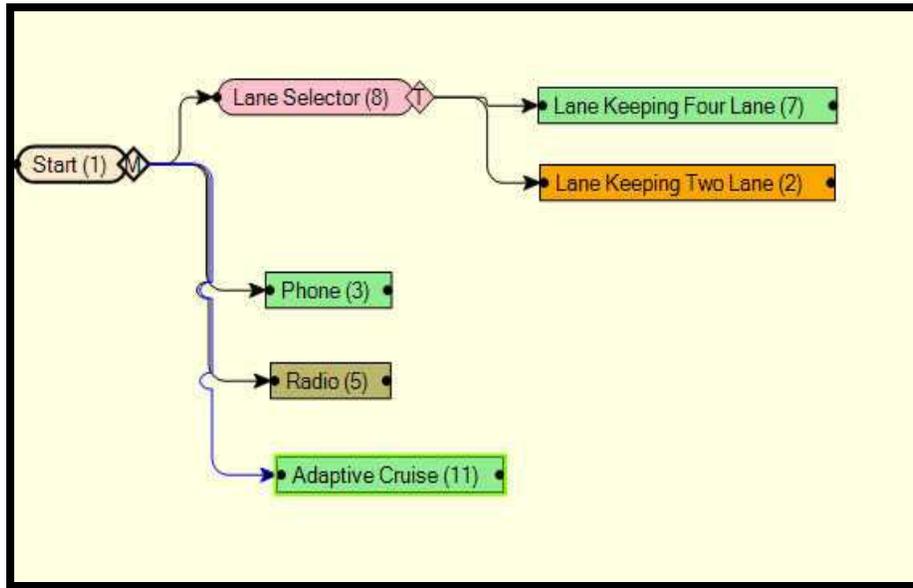


Figure 8: Upper Level Network for MicroSaint Discrete Event Simulation

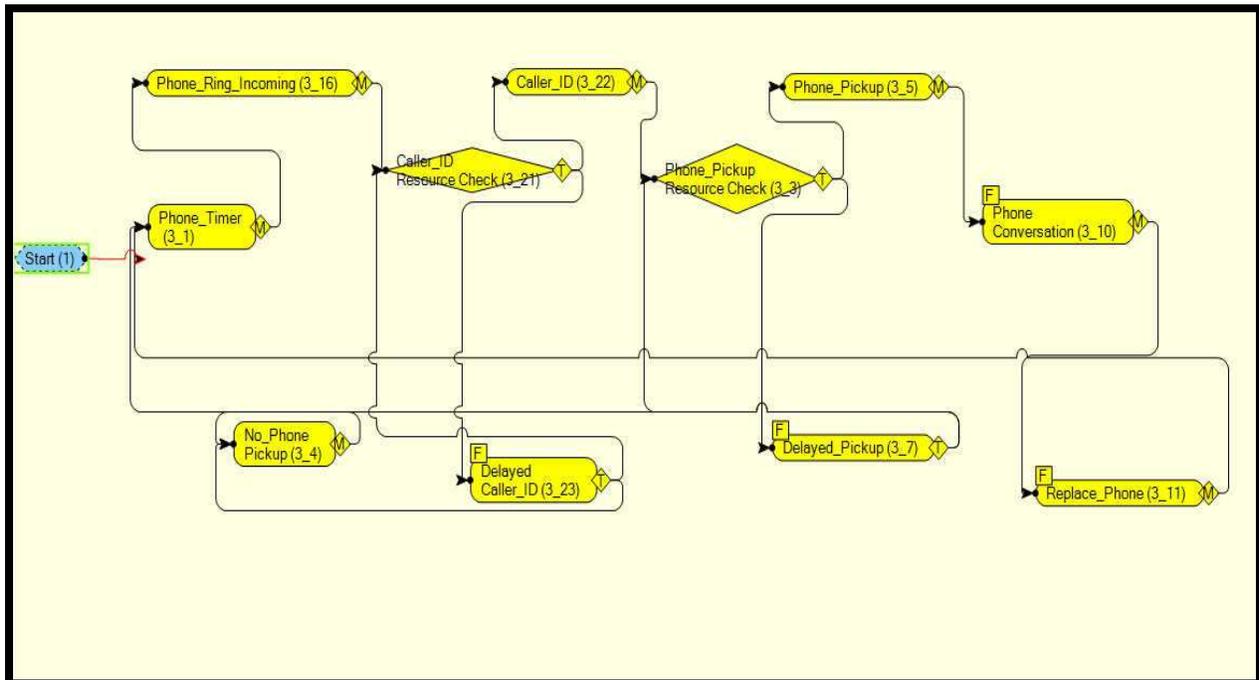


Figure 9: Example Sub-Network for MicroSaint Discrete Event Simulation – Phone Call

The animated output of this model contained graphs showing the workload for each of the modeled dimensions. Figure 10 shows the animated output.

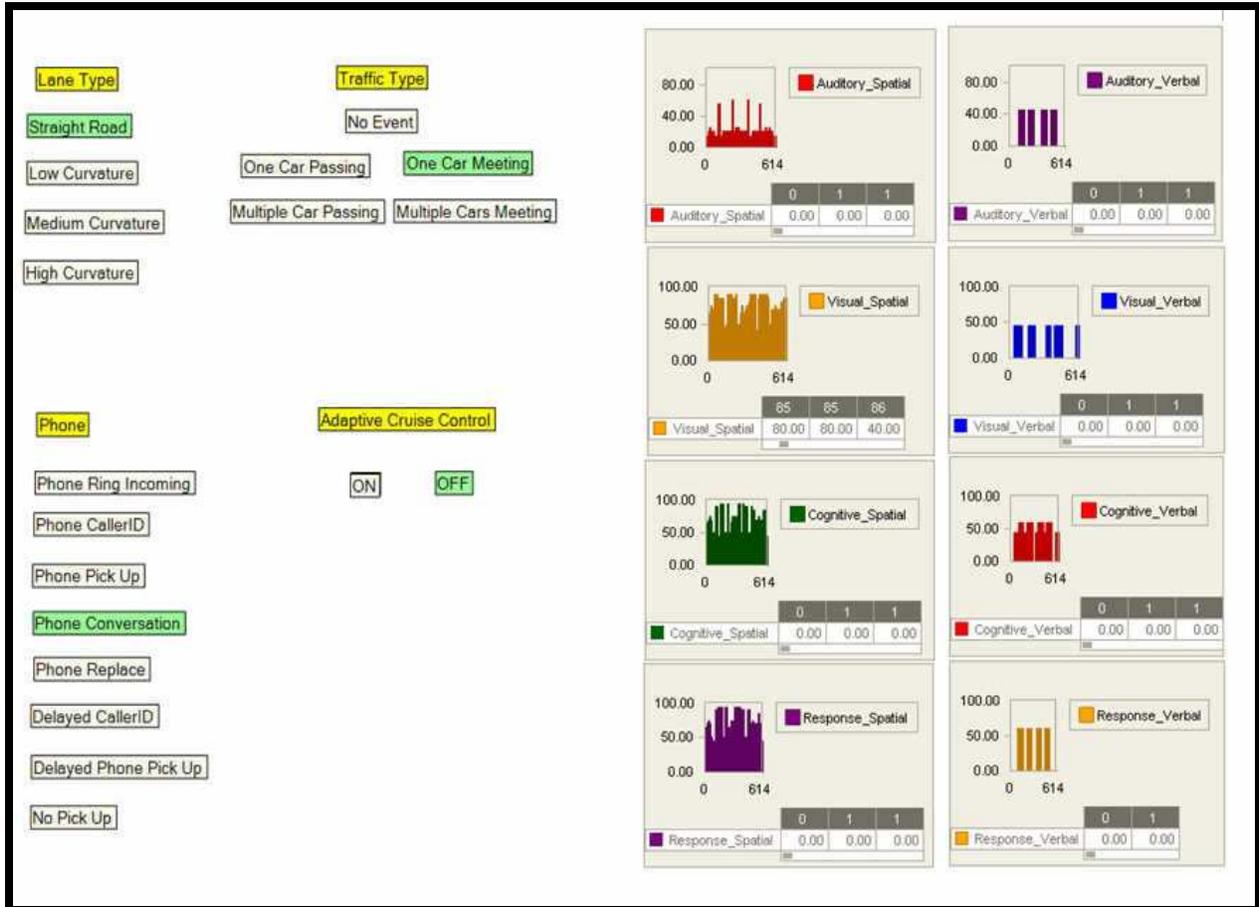


Figure 10: Animated Output for MicroSaint Discrete Event Simulation

This study did not continue with the simulation development after data collection.

3.5 Task Descriptions

The study of interest was comprised of three types of tasks. Subjects participating in the study performed the basic tasks of lanekeeping and traffic avoidance as well as distraction tasks, meant to simulate a vehicle navigation system.

3.5.1 Lanekeeping Task

The driving scenario in this experiment was composed of a lanekeeping task and a traffic avoidance task. The lanekeeping task was performed on a 13-mile long, rural two-lane road with straight sections, low, medium, and high curves. The low, medium, and high curves were all standardized to remove possible confounds to the experiment and were separated with segments of empty straight roadway. Low curves had radii of 1250 feet, medium curves had radii of 625 feet, and high curves had radii of approximately 417 feet. Additionally, while some of the road segments curved to the right and some curved to the left, the direction of curvature was assumed to have no effect on the driver's workload. The maximum speed of the simulation was set to 60 miles per hour, and at a constant speed of 60 miles per hour, the scenario lasted approximately 12.5 minutes (with the practice run lasting approximately 8 minutes at 60 miles per hour).

3.5.2 Traffic Avoidance Tasks

A total of twenty-four traffic events, called traffic avoidance tasks, occurred during the driving scenario. These events took place on various road curvatures and were one of two types: single car meeting or single car overtaking. In the driving simulation program, events were written according to distance instead of time, so even if individual drivers' speeds varied, the same events occurred at the same point in the simulation every time. The complete code of the practice scenario can be found in Appendix G, while the code for this scenario can be found in Appendix H. The driving scenario began on a straight road with no traffic event, as shown in Figure 11. At any point in the simulation, the driver was assumed to experience the minimum possible workload during this combination of lanekeeping task and traffic avoidance task.



Figure 11: Straight Road, No Traffic Avoidance Task

In this situation, the expected demand values were found in a single line of the demand matrix, as shown in Table 4.

Table 4: Straight Road, No Traffic Avoidance Task - Workload Values

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping _Straight	10	15	0	15

For this baseline condition, conservative values for visual focal, cognitive spatial and response spatial demands were chosen to represent the lowest possible workload values in their category.

The combinations of lanekeeping tasks and traffic avoidance tasks that followed were chosen to correspond to all combinations of rows in the demand matrix. For example, the workloads for a medium curvature road with a meeting task would correspond to the sum of the Lane Keeping_Curvature_Med and 2_Lane_One_Car_Meeting rows in the matrix. Similarly, the workloads for a high curvature road with an overtaking task would be equal to the sum of the Lane Keeping_Curvature_High and 2_Lane_One_Car_Overtaking rows. Images of these combinations can be found below in Figures 12 and 13.



Figure 12: Medium Curve, Meeting Task



Figure 13: High Curve, Overtaking Task

The total demands for these two examples are shown in Tables 5 and 6.

Table 5: Medium Curve, Meeting Task

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping_Curvature_Med	30	25	0	35
2_Lane_One_Car_Meeting	25	15	0	15
Workload Sums	55	40	0	50

Table 6: High Curve, Overtaking Task

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping_Curvature_High	40	30	0	45
2_Lane_One_Car_Overtaking	20	20	0	15
Workload Sums	60	50	0	60

The cognitive verbal values generated from the demand matrix were anticipated to remain zero throughout the driving scenario, except for during navigation tasks, because the other events did not involve verbal processing. Each event had a specified duration, shown in the tables of Appendix I and Appendix J.

3.5.3 Distraction Tasks

All of the distraction tasks were presented using the second computer monitor and keypad and required that the driver divide his or her attention between the driving task at hand and the distraction task. Each task consisted of a simple roadmap and a question which required numerical input. The driver was signaled to begin each task via an auditory cue, a simple .wav file placed in the simulation 50 feet prior to the distraction task. If the distraction task was not completed before the next task was scheduled to begin, no response was recorded for that task. The 17 distraction tasks were evenly distributed across the curvatures throughout the driving scenario, with the tasks beginning in the middle two-thirds of their curve. Appendix I and Appendix J also include placement of these tasks within the traffic events. The distraction tasks were also divided into three levels of difficulty: low, medium, and high.

Low difficulty distraction tasks presented a map to the driver with a red arrow near the bottom of the screen. This arrow would point north, along a vertical road on the map. The task would ask the question, "What is the next right (left) turn?" After reading the question, the driver would choose the correct response from one of four multiple-choice answers and input that choice on the keypad. The following Figure 14 shows a low difficulty distraction task.

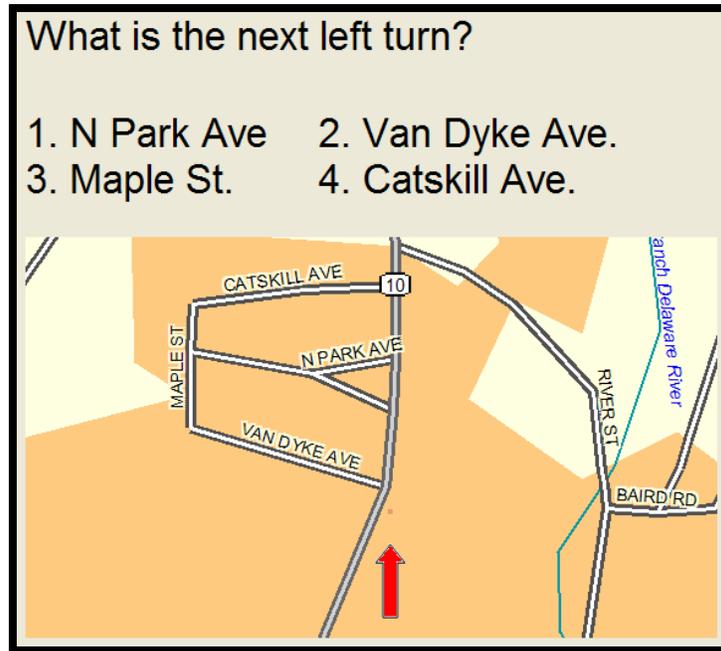


Figure 14: Low Difficulty Distraction Task – What is the next left turn? (Answer: 2)

If this low difficulty distraction task were to occur on a medium curve during an overtaking traffic avoidance task, the following workload sums would result (see Table 7).

Table 7: Medium Curve, Overtaking Task with Low Difficulty Distraction Task

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping_Curvature_Med	30	25	0	35
2_Lane_One_Car_Overtaking	20	20	0	15
Navigation Low Difficulty	15	20	80	25
Workload Sums	65	65	80	75

Medium difficulty tasks focused on the four cardinal directions. All medium difficulty maps contained a red compass which pointed north. Drivers performing a medium difficulty task would be required to select either North, South, East, or West in answer to a question such as “Road X is _____ of Road Y.” This would require the driver to first find Road X and Road Y and then determine the relationship between those two roads. Because the questions for these maps were assumed to require more visual and cognitive effort than those questions for the low difficulty maps, the visual focal and cognitive spatial demands increased in the demand matrix. The following Figure 15 shows a medium difficulty distraction task.

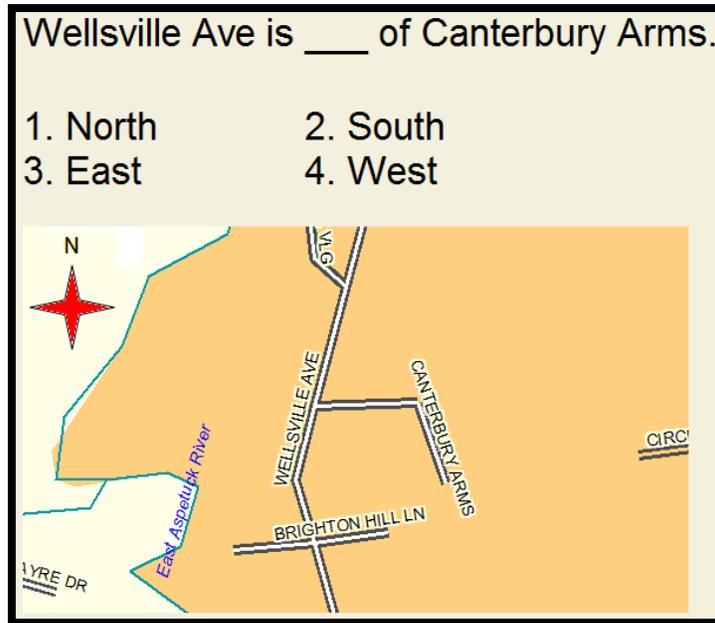


Figure 15: Medium Difficulty Task – Wellsville Ave is _ of Canterbury Arms. (Answer: 4)

If this medium difficulty distraction task were to occur on a medium curve during an overtaking traffic avoidance task, the following workload sums would result (see Table 8).

Table 8: Medium Curve, Overtaking Task with Medium Difficulty Distraction Task

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping_Curvature_Med	30	25	0	35
2_Lane_One_Car_Overtaking	20	20	0	15
Navigation Med Difficulty	25	30	80	25
Workload Sums	75	75	80	75

As compared to the demands associated with the low difficulty distraction task, the visual focal and cognitive spatial demands both increased by 10.

High difficulty distraction tasks had maps with only two answer choices (North/South, East/West, or Left/Right). The questions were similar to those used for the low and medium difficulty tasks, but in the high difficulty tasks, an addition or subtraction problem was presented below each of the two answer choices. For these high difficulty tasks, the driver was required to choose the correct answer to the question and then input the answer to the corresponding mathematics problem. Two examples of this are shown below in Figures 16 and 17.

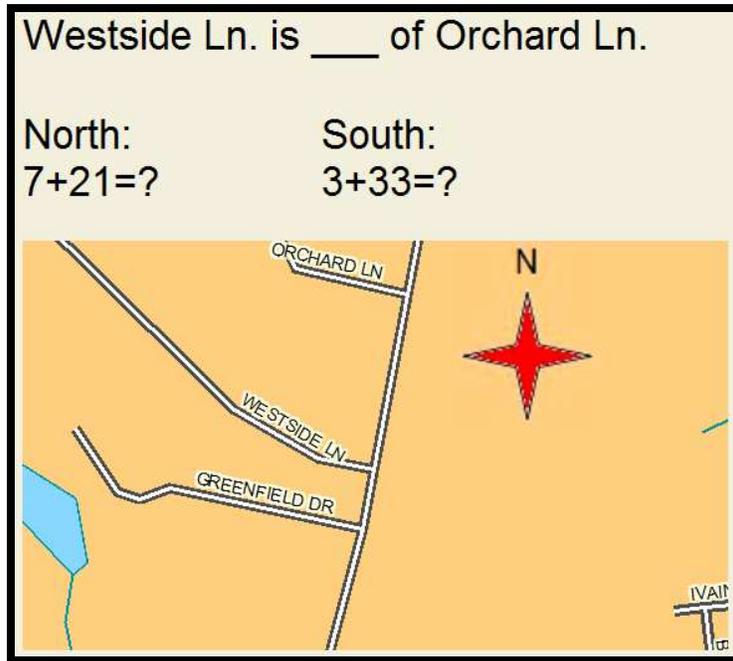


Figure 16: High Difficulty Distraction Task - Westside Ln is ___ of Orchard Ln. (Answer: $3+33=36$)

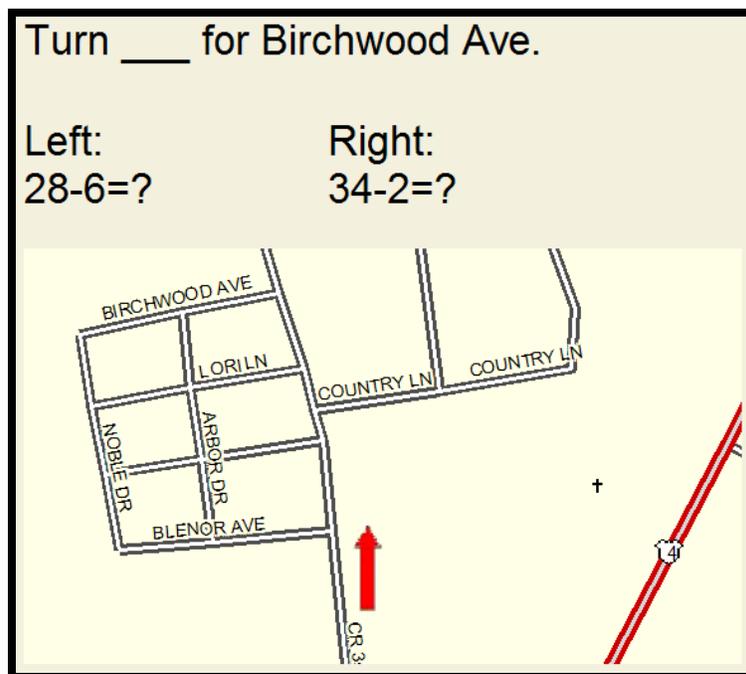


Figure 17: High Difficulty Distraction Task - Turn ___ for Birchwood Ave. (Answer: $28-6=22$)

These high difficulty tasks were considered more difficult than both the low and medium difficulty tasks because the subject was assumed to require more than one glance at the navigation screen and more cognitive processing before completing the task. If either of these high difficulty distraction tasks were to occur on a medium curve during an overtaking traffic avoidance task, the following workload sums would result (see Table 9).

Table 9: Medium Curve, Overtaking Task with High Difficulty Distraction Task

Tasks	Workloads			
	Perceptual	Cognitive		Response
	Vf	Cs	Cv	Rs
Lane Keeping_Curvature_Med	30	25	0	35
2_Lane_One_Car_Overtaking	20	20	0	15
Navigation High Difficulty	30	35	80	25
Workload Sums	80	80	80	75

As compared to the demands associated with the low difficulty distraction task, the visual focal and cognitive spatial demands both increased by 15. The various combinations of road curvature, traffic events, and distraction tasks enabled the analysis of workload values in the demand matrix. Each combination of curve, traffic, and distraction task was represented in either the practice or real scenarios so that workload values could be compared within, between, and among tasks. See Appendix K for images of all practice run distraction tasks and Appendix L for images of all distraction tasks from the real run.

3.6 Data Collection

To compare the demand matrix values for a given situation with the results from the driving experiment, variables deemed dependent on the driver's workload were established. The dependent variables in both the navigation program and the driving simulation were used to validate the demand matrix for each event. Dependent measures were absolute horizontal lane position, absolute velocity, lane position root-mean squared (RMS) error and velocity RMS error (both measures of variance), time between the beginning of a navigation event and the first keystroke (answer time), time from first keystroke to last keystroke, and correct or incorrect responses to the distraction tasks.

As the matrix workloads for an event increased, a parallel increase in incorrect responses, RMS errors, or task times or a decrease in absolute velocity was expected, and vice versa. Before the experiment, the likelihood of a crash was discussed and all paths to minimize this likelihood were taken. However, in the event of a crash, the STISIM program would automatically place the vehicle back on the road where the accident occurred. The drivers were then asked to regain their speed and complete the experiment. The section of data prior to, including, and after the crash, until the driver had regained a constant velocity, was omitted from analysis.

Like the demand matrix presented previously, the original demand matrix (see Appendix A) also included values for distraction tasks other than navigation tasks, such as cellular telephone, radio, and climate control tasks, as well as values for demand during different weather conditions. Although the implementation of these tasks and conditions would be valid, the scope of the experiment was narrowed to focus on the effects of the navigation tasks on driver workload.

4 RESULTS

Thirty-five of the 44 subjects' data were used in the analysis of the results for the second 13-mile driving scenario. Nine of the 44 subjects had driven the simulator before, so the data for those nine subjects were excluded from analysis to prevent variations due to differing experience levels. Data points associated with vehicle crashes were also removed from the subjects' raw data. Finally, data points more than 2.5 standard deviations from the mean were deemed outliers and removed from the data set.

Two metrics of workload were used for the analysis. The first metric, performance (in terms of the root-mean squared error of lane position), was said to decrease as the RMS error increased on the y-axis in the following graphs. The second metric, answer time, was also said to show a decrease in performance as the value on the y-axis increased. Because the maximum speed of the simulation was set to 60 miles per hour, some subjects never accelerated or decelerated after their initial acceleration to 60 miles per hour. Therefore, the root-mean squared error of velocity was not used as a metric in the analysis because of its lack of sensitivity to subjects who used the maximum speed as a form of cruise control.

4.1 Analysis of Variance

A three-way analysis of variance was performed for the performance measure lane RMS error as well as for the answer time metric. The ANOVAs were additionally blocked by subject. Tables 10 and 11 below show the results of the analyses of variance.

Table 10: Three-Way ANOVA for Lane RMS Error, Blocked by Subject

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Curve	3	2261.6470	753.8823	66.18	<.0001	36.43%
Traffic	2	18.9436	9.4718	0.83	0.4357	
Task	3	2221.0772	740.3591	65.00	<.0001	
Curve * Traffic	6	103.6536	17.2756	1.52	0.1694	
Curve * Task	6	495.2345	82.5391	7.25	<.0001	
Traffic * Task	5	687.0385	137.4077	12.06	<.0001	
Curve * Traffic * Task	2	29.2185	14.6093	1.28	0.2778	
Subject	34	671.9774	19.7621	1.73	0.0060	

Table 11: Three-Way ANOVA for Answer Time, Blocked by Subject

Source	DF	Type III SS	Mean Square	F Value	Pr > F	R-Square
Curve	3	1474.3348	491.4449	67.20	<.0001	70.74%
Traffic	2	150.6232	75.3116	10.30	<.0001	
Task	2	1210.5741	605.2870	82.77	<.0001	
Curve * Traffic	2	672.7143	336.3571	46.00	<.0001	
Curve * Task	1	37.6689	37.6689	5.15	0.0236	
Traffic * Task	1	1.8523	1.8523	0.25	0.6150	
Subject	34	2564.3342	75.4216	10.31	<.0001	

4.2 Primary Factors

As shown in the ANOVA tables, several primary factors were significantly different at the 95 percent level. The following three sections discuss these significant differences with respect to lane RMS error and answer time.

4.2.1 Curvature

Lane curvature was a significant factor in both the lane RMS error ANOVA (as seen in Table 10) and the answer time ANOVA (as seen in Table 11). The following figure (Figure 18) shows the mean value of performance and 95 percent confidence interval for lane RMS error in terms of road curvature. A significant difference was found between the performance on high curvature roads (8.2915) and performance on medium curvature roads (6.6331). Both of these means were also significantly different from the performance on low curvature (5.6257) and straight roads (5.1909), although no difference was found between performance on low curvature and straight roads. Figure 18 highlights the upward trend in lane RMS error observed for roads of the four types of curvature.

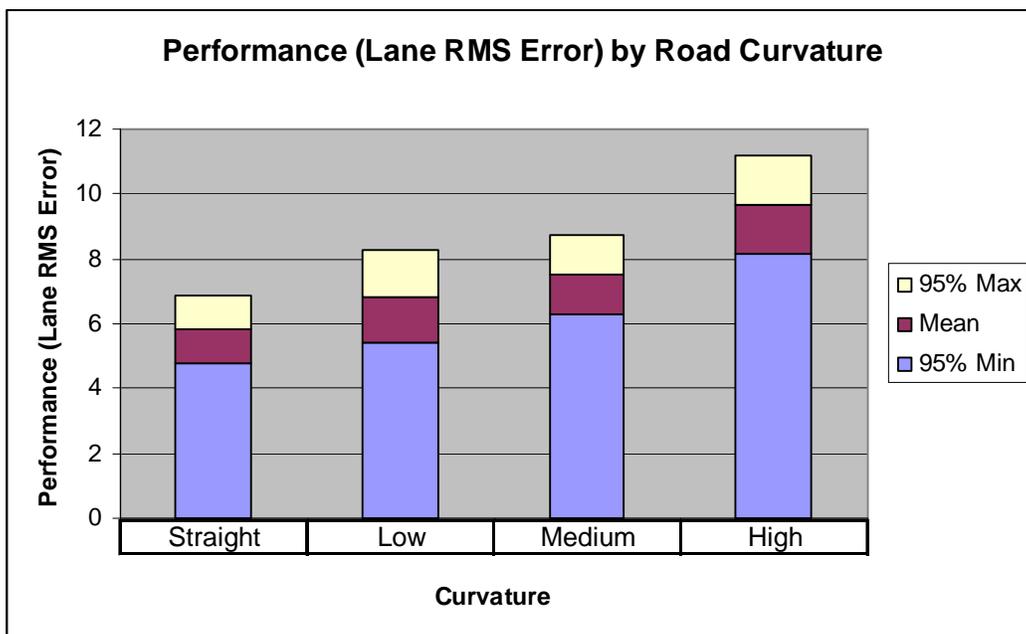


Figure 18: Performance by Curvature

In terms of mean answer times, a significant difference was found between high (14.0545) and low (9.2104) curvature roads. These means were also significantly different from both the value for medium curvature roadway (7.8579) and straight roadway (8.2033). However, medium curvature and straight roadway means were not significantly different. The

lack of significant difference between medium curve and straight roads could be due to drivers accommodating for the increase in curvature by concentrating harder, thus lowering their effective workload. This accommodation may not have occurred for low curvature roads, but when the curvature increased to medium, drivers may have focused more on the lanekeeping task. When the curvature again increased to high, the drivers may not have been able to accommodate for the entirety of the workload increase, thus yielding the highest mean answer times. Figure 19 shows this relationship.

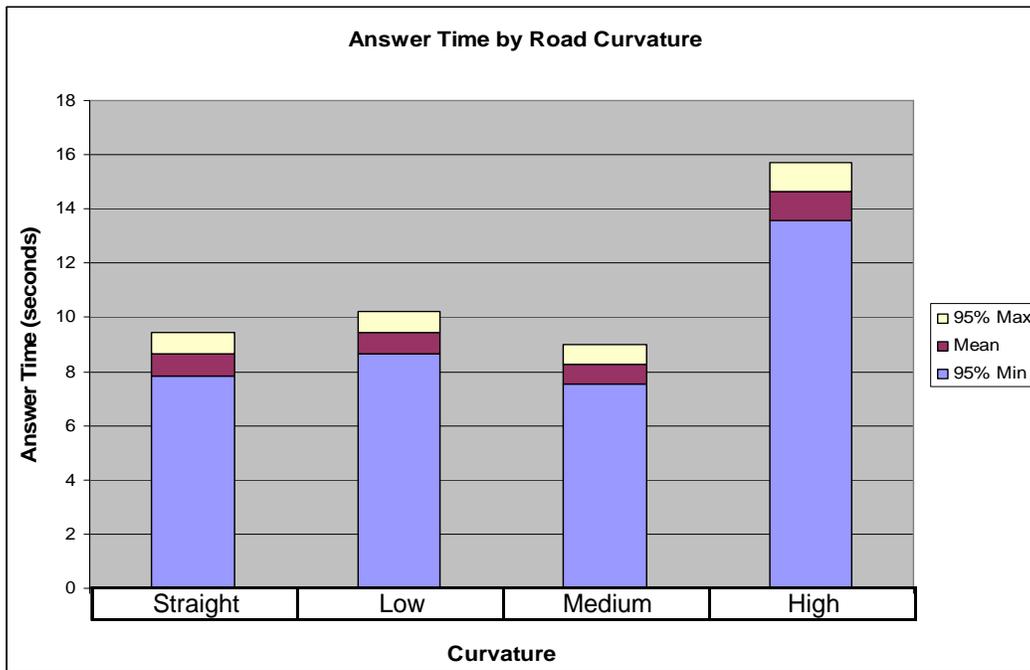


Figure 19: Answer Time by Curvature

4.2.2 Traffic Type

The effect of traffic was not significant in the lane RMS error analysis of variance (Table 10) (see Figure 20). It was, however, significant in the answer time analysis of variance (Table 11). The answer time means for no traffic (10.9145), overtaking (10.1979), and meeting events (8.7002) were all significantly different. Figure 21 shows the means and 95 percent confidence interval for traffic type in terms of answer time.

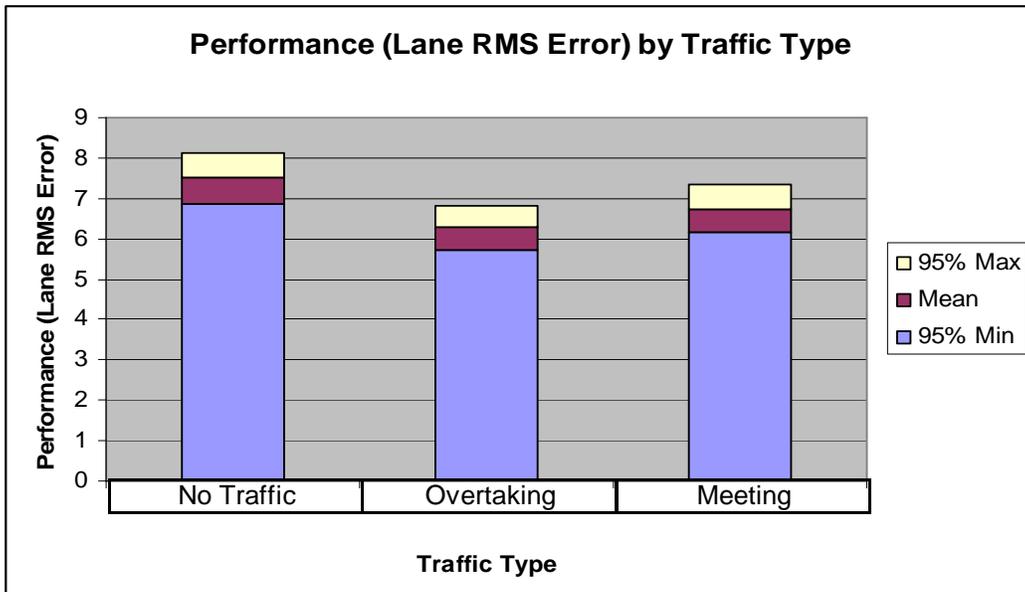


Figure 20: Performance by Traffic Type

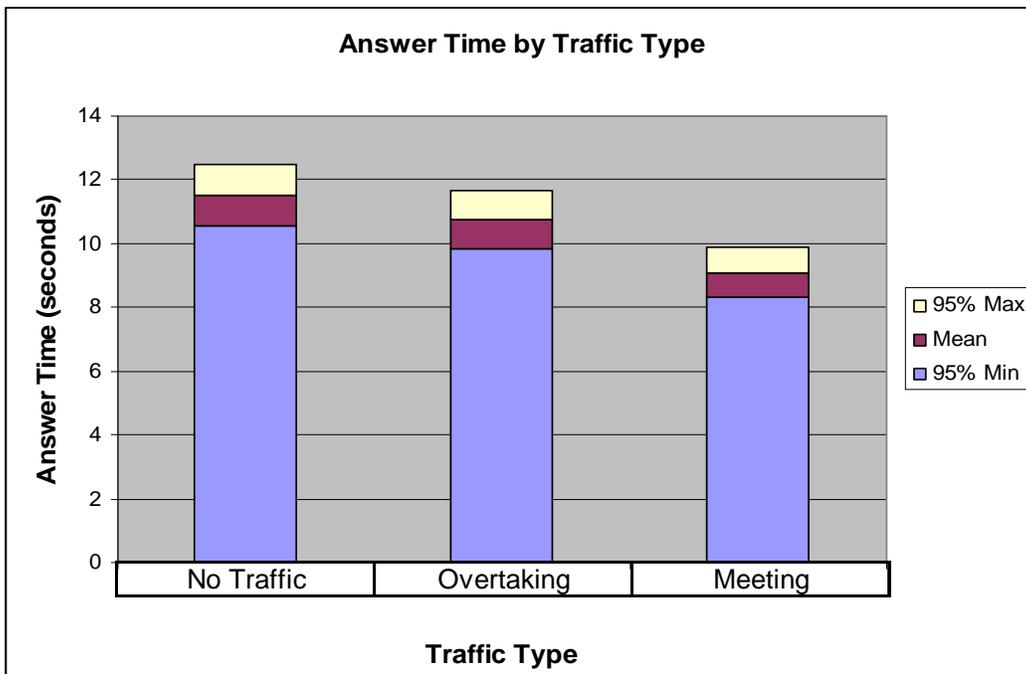


Figure 21: Answer Time by Traffic Type

Figure 21 shows that the mean answer time actually decreased as traffic was added to an event, indicating that subjects focused more on staying in the center of the lane as they encountered other vehicles.

4.2.3 Task Difficulty

Task difficulty was another significant primary factor in both analyses of variance (Tables 10 and 11). The mean lane RMS errors for no task (4.9537) and high difficulty task (6.8408) were significantly different, and both were significantly different from the low (8.2784) and medium difficulty (7.7122) task means. Low and medium difficulty task mean lane RMS error values were, however, not significantly different. See Figure 22 for a visual representation of these means.

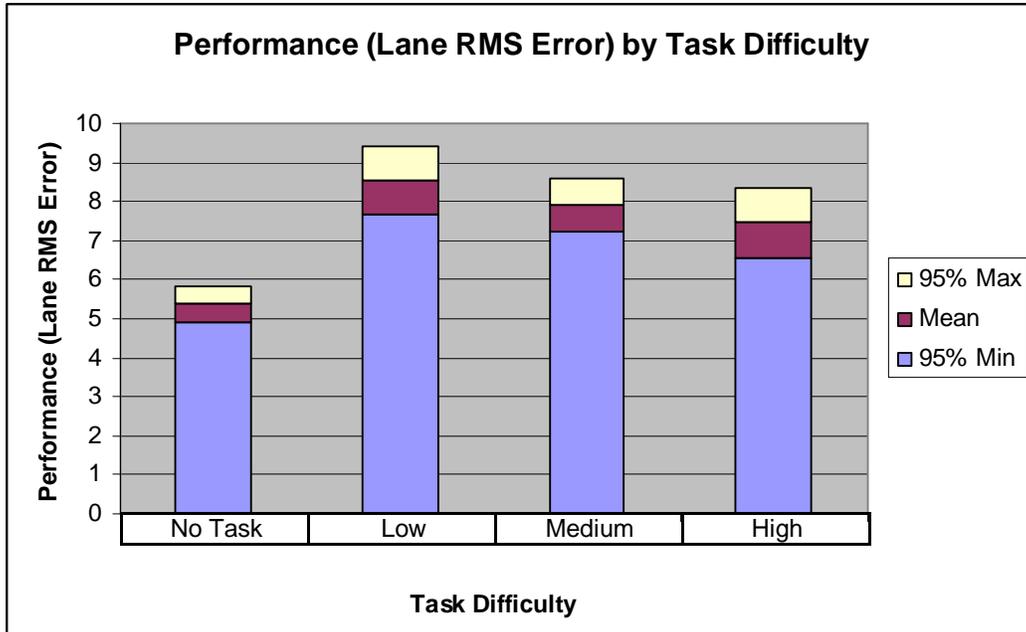


Figure 22: Performance by Task Difficulty

Although the performance values in Figure 22 for no task and low, medium, or high task should be different, the trend seemed to indicate that the classifications of low, medium, and high difficulty did not accurately predict performance for those tasks (the trend should have increased, not decreased). Therefore, in later analyses, the task types were only divided into two categories, no task and task.

In terms of answer time, the means for low (7.1415), medium (12.1375) and high (11.0064) task difficulty were all significantly different. Figure 23 shows these means.

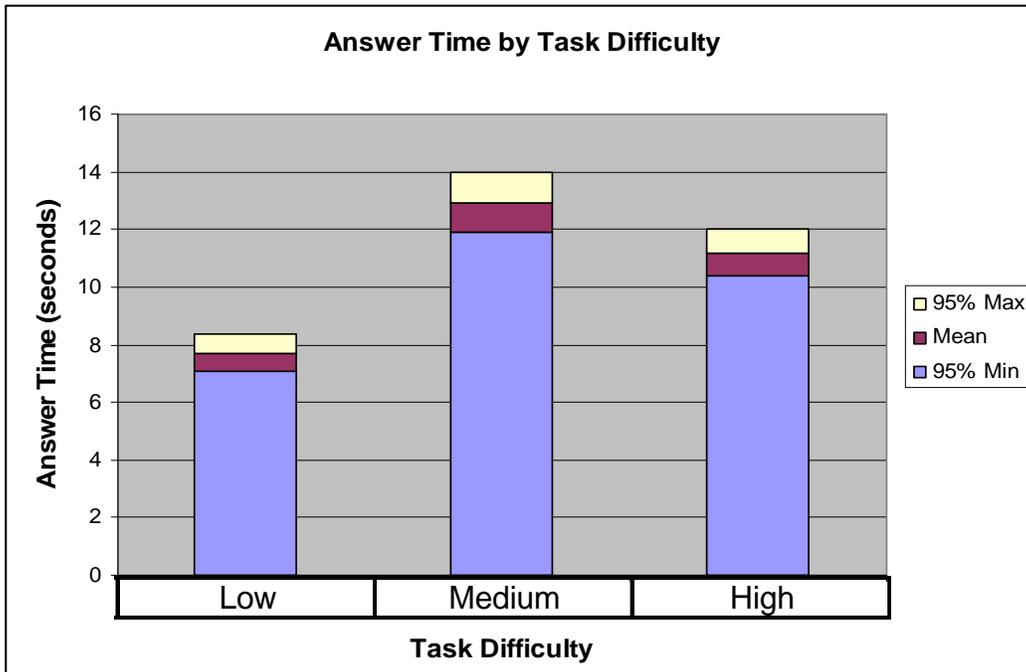


Figure 23: Answer Time by Task Difficulty

According to the answer time metric, medium difficulty tasks, which consisted of a visual search process, took longer for subjects to perform than did high difficulty tasks, which were comprised of a visual search and a cognitive (mental math) process. This observation could mean that the visual search element of this task was as demanding or even more demanding than the cognitive component of the high difficulty task.

4.3 Two-Way Interactions

In addition to the effects of primary factors in the analyses of variance, several two-way interactions were statistically significant. The mean and standard deviations for lane RMS error and answer time for all two-way interactions can be found in Appendix M.

4.3.1 Curvature and Traffic

The effect of the combination of curve and traffic was not significant according to the lane RMS error ANOVA (Table 10); however, the effect was significant according to the answer time ANOVA (Table 11). Figure 24 shows the non-significant differences in mean lane RMS error, while Figure 25 shows the significant differences in mean answer time.

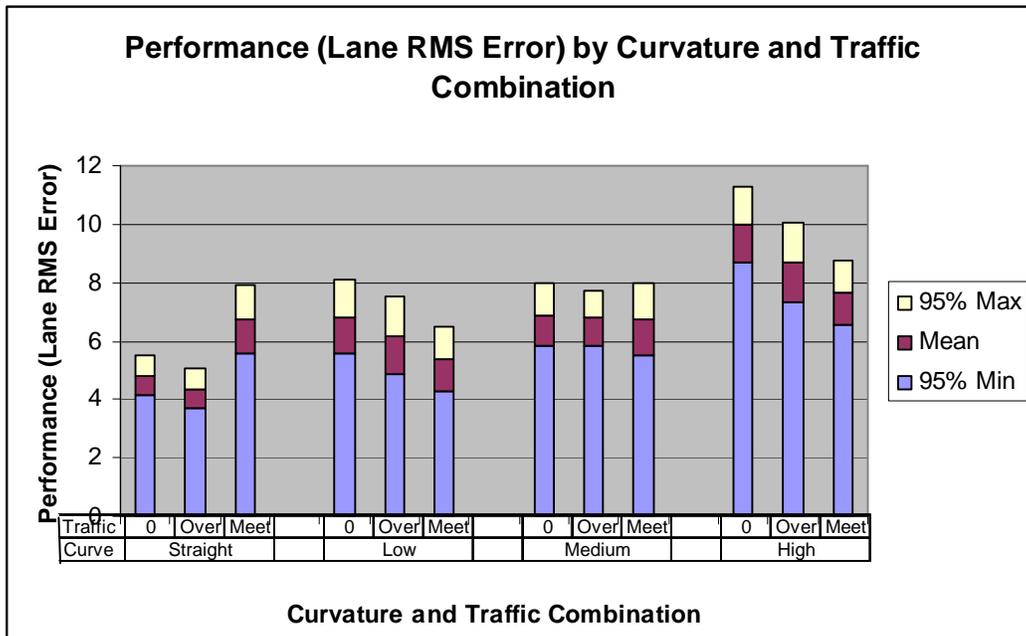


Figure 24: Performance by Curvature and Traffic

Apart from the data for the straight road in Figure 24, the trend of mean performance (lane RMS error) resulting from a combination of curvature and traffic event seemed to indicate that drivers became more focused on staying in the center of their lane as they encountered other vehicles for all road curvatures.

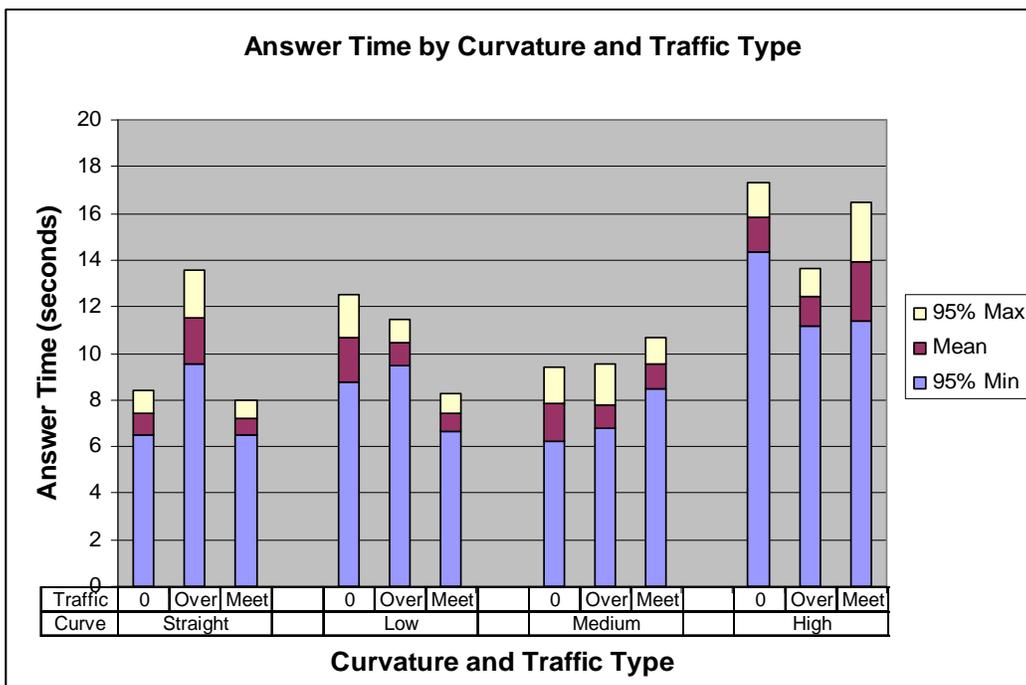


Figure 25: Answer Time by Curvature and Traffic

4.3.2 Curvature and Task

Curvature and task interactions were significant for both analyses of variance (Tables 10 and 11). Figure 26 shows the interaction for lane RMS error and Figure 27 shows the interaction for answer time.

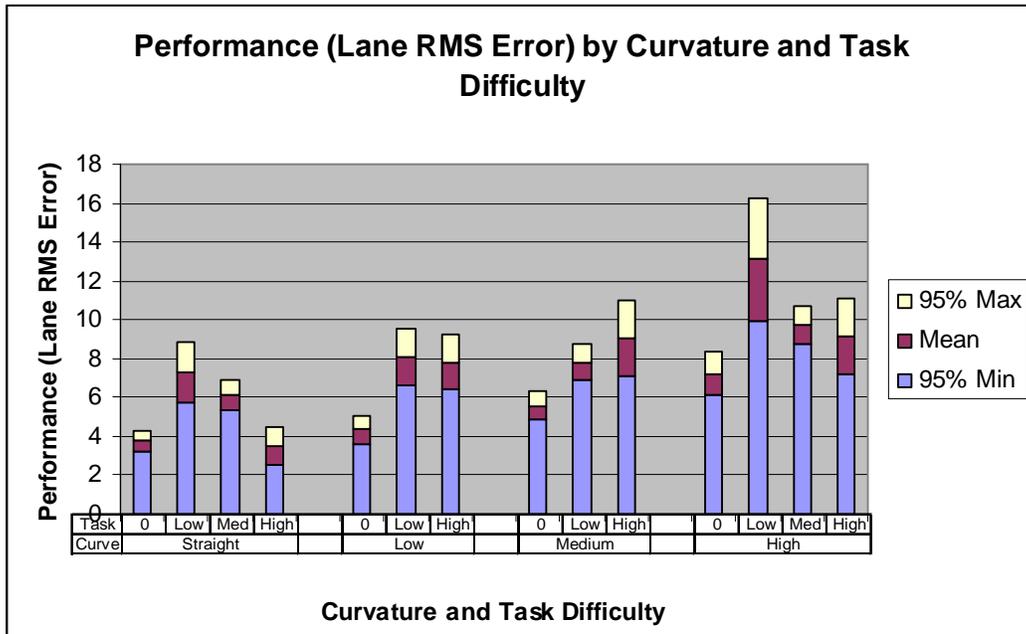


Figure 26: Performance by Curvature and Task

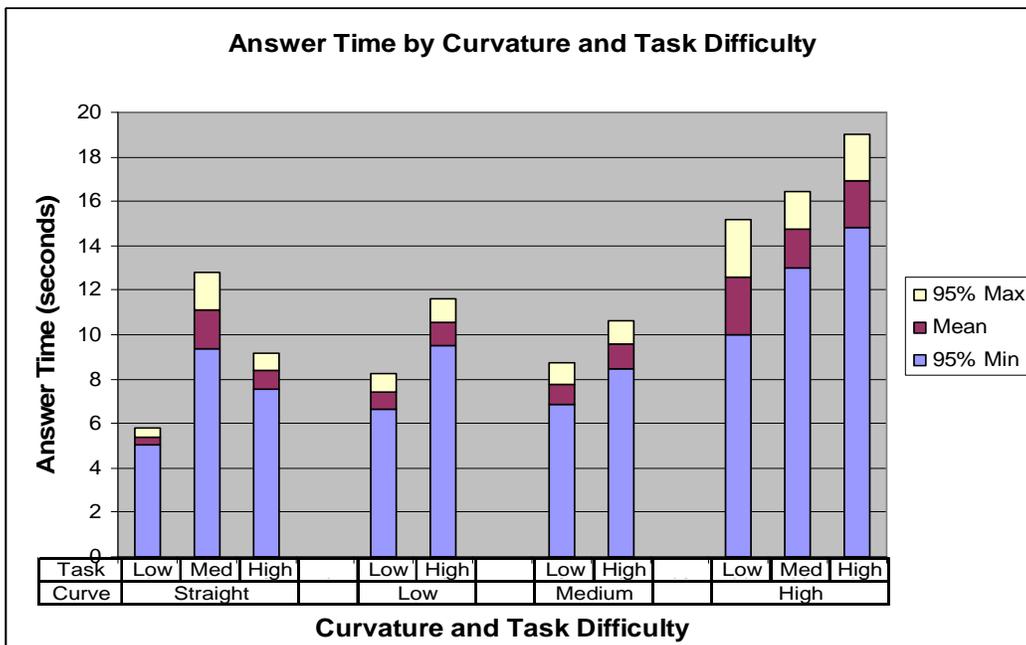


Figure 27: Answer Time by Curvature and Task

4.3.3 Traffic and Task

Traffic type and task difficulty interactions were only significant for the lane RMS error ANOVA (Table 10). Figure 28 illustrates these significant interactions, while Figure 29 shows the non-significant interactions for answer time.

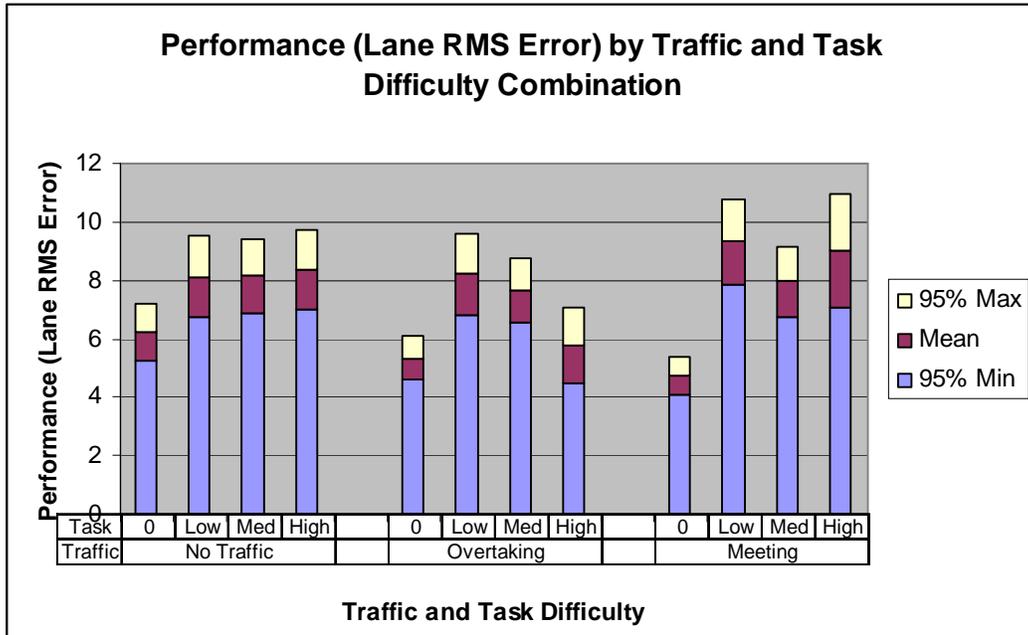


Figure 28: Performance by Traffic and Task

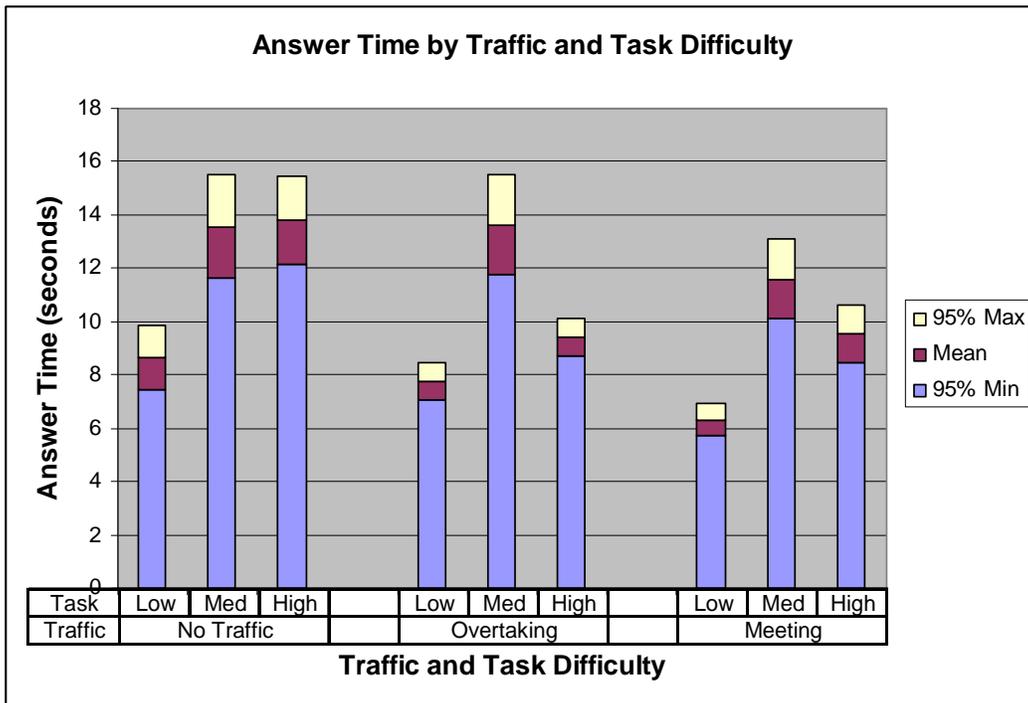


Figure 29: Answer Time by Traffic and Task

4.4 Three-Way Interactions

Because this experiment did not use a balanced design, the three-way interaction for the answer time ANOVA was not complete. In addition, the three-way interaction was not significant for the lane RMS error ANOVA (see Table 10). Although no three-way interactions were analyzed, acquiring these interactions was not of interest in this experiment due to the difficulty associated with interpreting the results and implications of a three-way interaction.

4.5 Performance Measure and Workload Comparisons

Next, the means of the performance and answer time data gathered for each of the events were compared to the expected workload for those events.

4.5.1 Regressions

The first comparison was performed using a simple linear regression for each of the workload categories as well as for the sum of visual focal, cognitive spatial, and response spatial workload values. Further comparisons were made using multiple linear regressions. Figures 30 through 34 show the simple linear regressions for performance (lane RMS error), while Table 12 shows the values for the simple and multiple linear regressions.

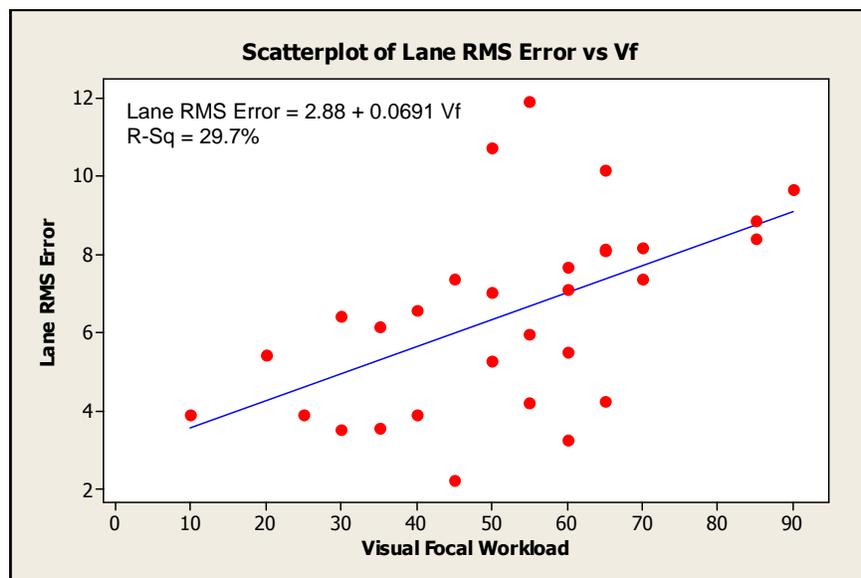


Figure 30: Regression of Performance versus Visual Focal Workload

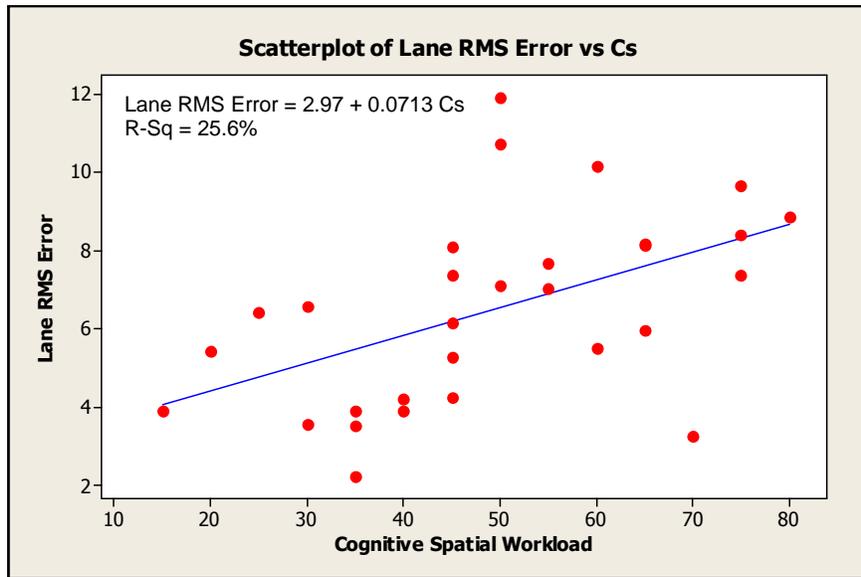


Figure 31: Regression of Performance versus Cognitive Spatial Workload

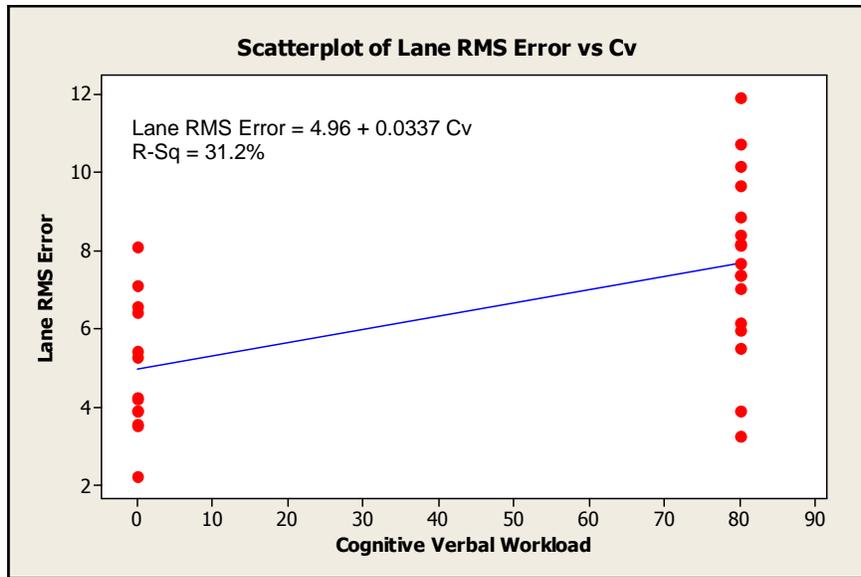


Figure 32: Regression of Performance versus Cognitive Verbal Workload

Figure 32 shows the binary nature of the values assigned for cognitive verbal workload. The value of cognitive workload in the demand matrix was assumed to be zero when the subjects were not performing navigation tasks and 80 when subjects were performing navigation tasks. In Figure 32 the regression line had a relatively high R-Square value, though this was due to the concentration of data points at either end of the regression line.

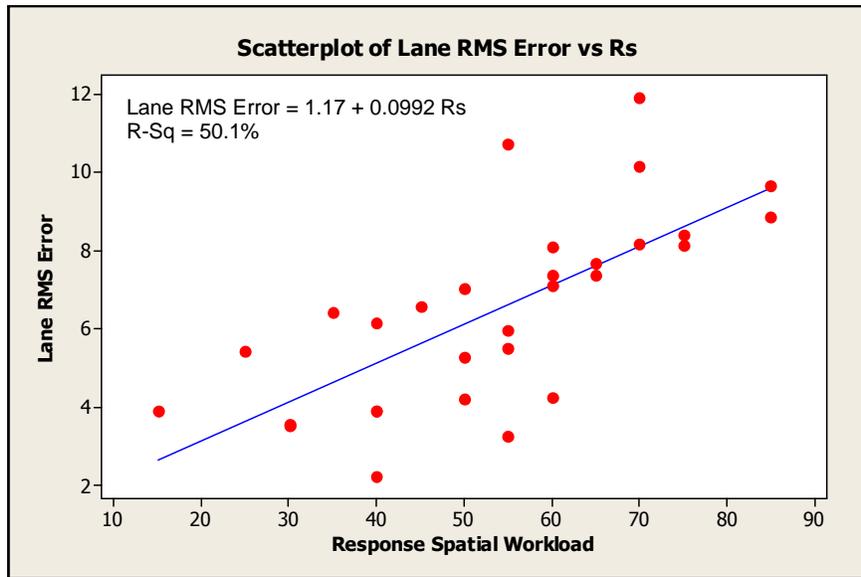


Figure 33: Regression of Performance versus Response Spatial Workload

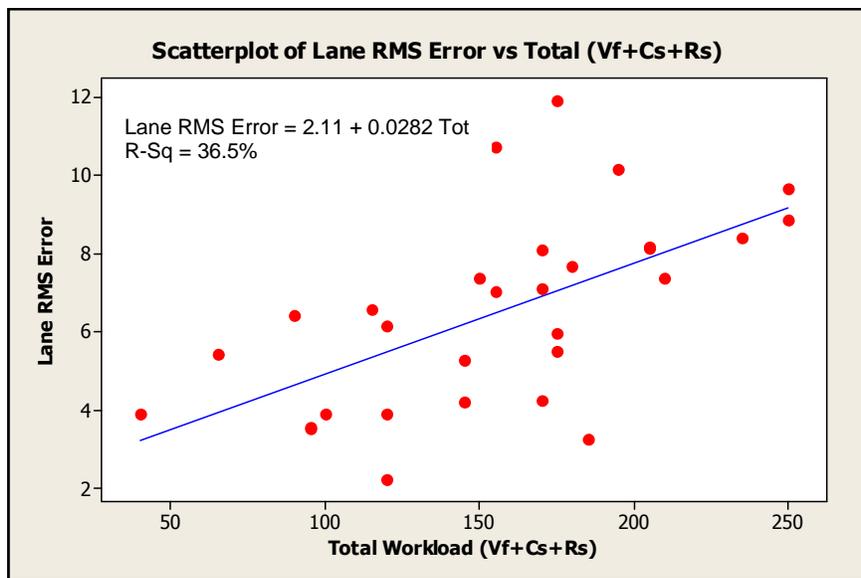


Figure 34: Regression of Performance versus Total Workload (Vf + Cs + Rs)

The following table (Table 12) shows the regression values for both the simple and multiple linear regressions of performance (lane RMS error).

Table 12: Regression Values for Performance (Lane RMS Error)

Simple Linear Regressions					
Performance (Lane RMS Error) versus	Visual Workload	Cognitive S. Workload	Cognitive V. Workload	Response Workload	Total (Vf+Cs+Rs)
Constant	2.88	2.97	4.96	1.17	2.11
Workload Coefficient	0.0691 (Vf)	0.0713 (Cs)	0.0337 (Cv)	0.0992 (Rs)	0.0282 (Total)
Significance	p = 0.002	p = 0.004	p = 0.001	p = 0.000	p = 0.000
R-Squared	29.7%	25.6%	31.2%	50.1%	36.5%
Multiple Linear Regressions					
Performance (Lane RMS Error) versus	Visual and Cognitive	Visual, Cognitive S., and Response	Visual, Cognitive S., Response, and Cognitive V.		
Constant	2.79	0.842	2.13		
Vf Coefficient	0.0592	-0.116	-0.0265		
Cs Coefficient	0.0122	-0.0297	-0.109		
Rs Coefficient		0.246	0.0243		
Cv Coefficient			0.187		
Significance	p = 0.008	p = 0.000	p = 0.000		
R-Squared	29.8%	63.7%	66.3%		

Figures 35 through 38 show the simple linear regression scatter plots for the answer time metric. Additionally, Table 13 displays the values for the simple and multiple linear regressions.

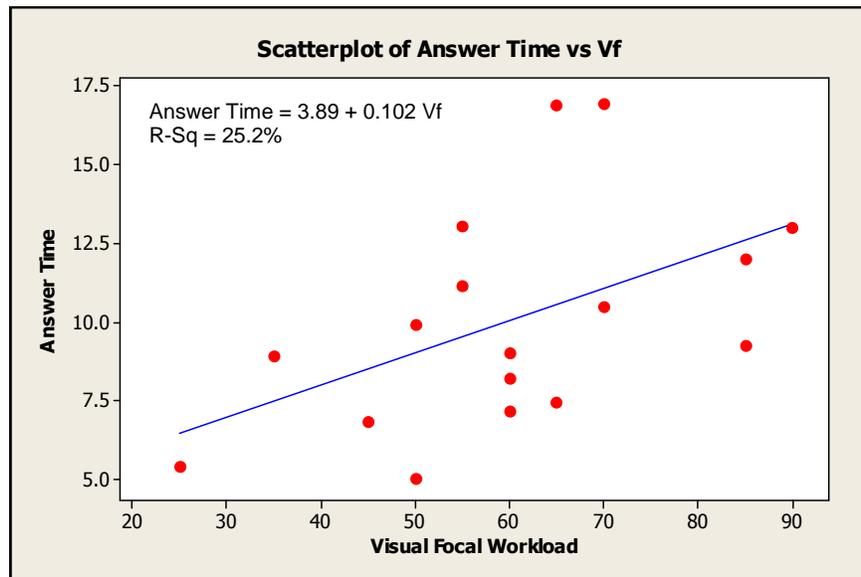


Figure 35: Regression of Answer Time versus Visual Focal Workload

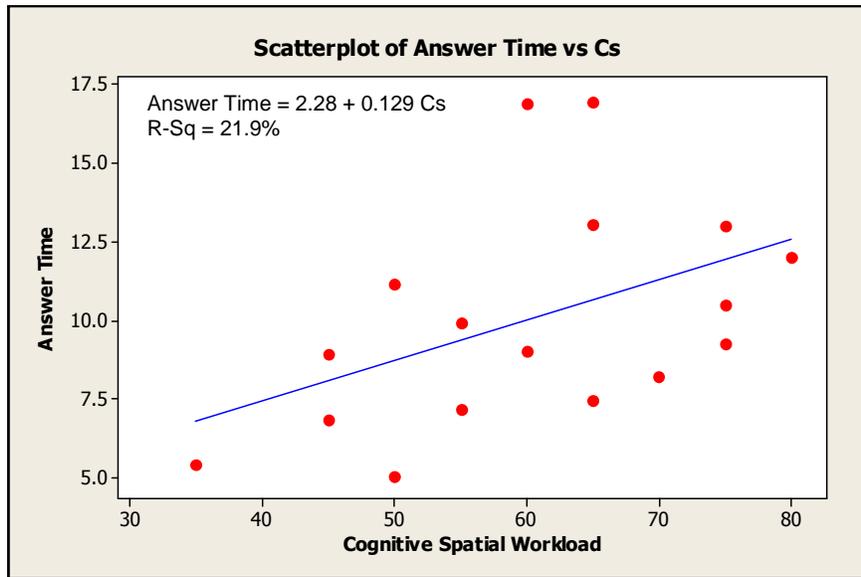


Figure 36: Regression of Answer Time versus Cognitive Spatial Workload

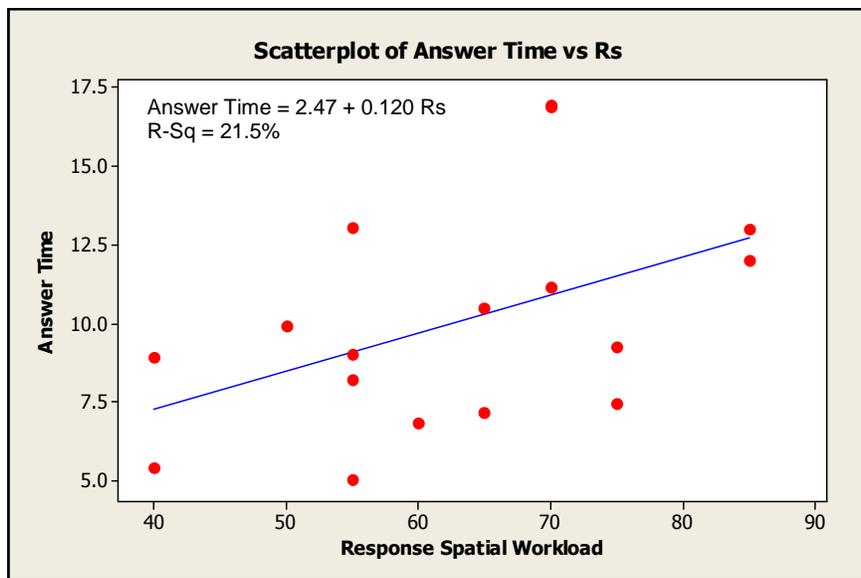


Figure 37: Regression of Answer Time versus Response Spatial Workload

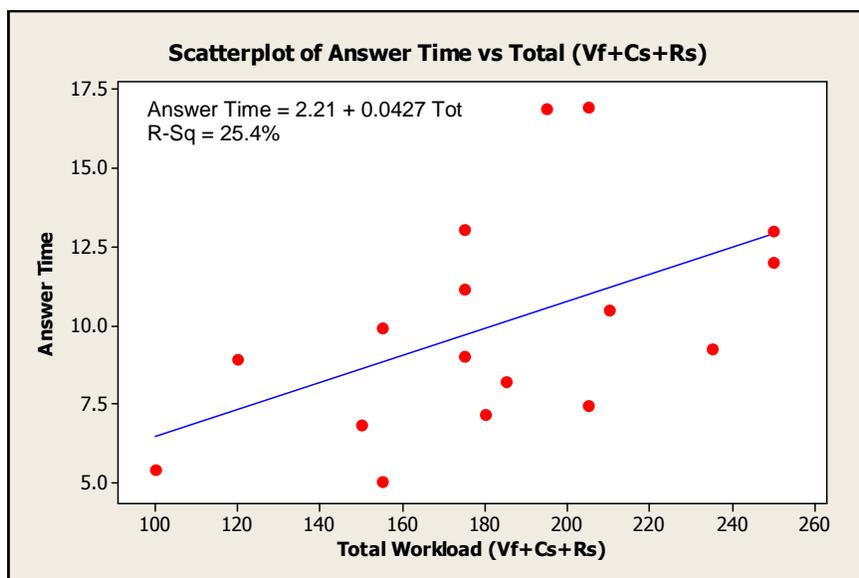


Figure 38: Regression of Answer Time versus Total Workload (Vf + Cs + Rs)

The following table (Table 13) contains the values for the simple linear and multiple regressions of answer time versus workload.

Table 13: Regression Values for Answer Time

Simple Linear Regressions				
Answer Time versus	Visual Workload	Cognitive S. Workload	Response Workload	Total (Vf+Cs+Rs)
Constant	3.89	2.28	2.47	2.21
Workload Coefficient	0.102 (Vf)	0.129 (Cs)	0.120 (Rs)	0.0427 (Total)
Significance	p = 0.040	p = 0.058	p = 0.061	p = 0.039
R-Squared	25.2%	21.9%	21.5%	25.4%
Multiple Linear Regressions				
Answer Time versus	Visual and Cognitive		Visual, Cognitive, and Response	
Constant	3.64		2.5	
Vf Coefficient	0.094		0.054	
Cs Coefficient	0.013		0.036	
Rs Coefficient			0.034	
Significance	p = 0.131		p = 0.267	
R-Squared	25.2%		25.4%	

Step-wise regressions for lane RMS error and answer time were also performed on the individual data points instead of the means. The best single variable regression for lane RMS error was the regression using response spatial workload (R-Sq = 16.98%, p < 0.0001). The two-variable regression resulting in the highest R-Square value was the regression using response spatial and visual focal workloads (R-Sq = 21.28%, p < 0.0001). For the step-wise regression on answer time, the sum of visual, cognitive, and response workloads resulted in the best single variable regression (R-Sq = 13.07%, p < 0.0001). The addition of the variable Max (the maximum of these three workloads) increased the R-Square value to 14.33% (p < 0.0001). Replacing the total variable (Vf+Cs+Rs) with the visual focal workload variable only

increased the R-Square value to 14.66% ($p < 0.0001$). Therefore, the single total variable (Vf+Cs+Rs) seemed to account for most of the variance in answer times.

4.5.2 Correlations

Further analysis was performed in the form of correlations between the means of the two performance measures as well as between the performance measures and the total workloads. The results of these correlations are shown in Table 14 for the relationship between the lane RMS error values and answer times. Every cell in the correlation tables show the Pearson correlation followed by the associated p-value. Correlations showing the relationship between lane RMS error and workloads can be found in Table 15, and those correlations showing the relationship between answer times and workloads can be found in Table 16.

Table 14: Correlation of Performance and Answer Time

Pearson correlation of Performance (Lane RMSE) and Time	0.149
p-value	0.000

Table 15: Correlations for Lane RMS Error, Vf, Cs, Cv, Rs, Total (Vf+Cs+Rs), Vf+Cs+Cv+Rs

	Lane RMSE	Vf	Cs	Cv	Rs	Total (Vf+Cs+Rs)
Vf	0.545 0.002					
Cs	0.506 0.004	0.897 0.000				
Cv	0.559 0.001	0.482 0.007	0.739 0.000			
Rs	0.708 0.000	0.941 0.000	0.877 0.000	0.621 0.000		
Total (Vf+Cs+Rs)	0.604 0.000	0.979 0.000	0.954 0.000	0.629 0.000	0.970 0.000	
Vf+Cs+Cv+Rs	0.646 0.000	0.843 0.000	0.951 0.000	0.875 0.000	0.905 0.000	0.927 0.000
Cell Contents: Pearson Correlation P-Value						

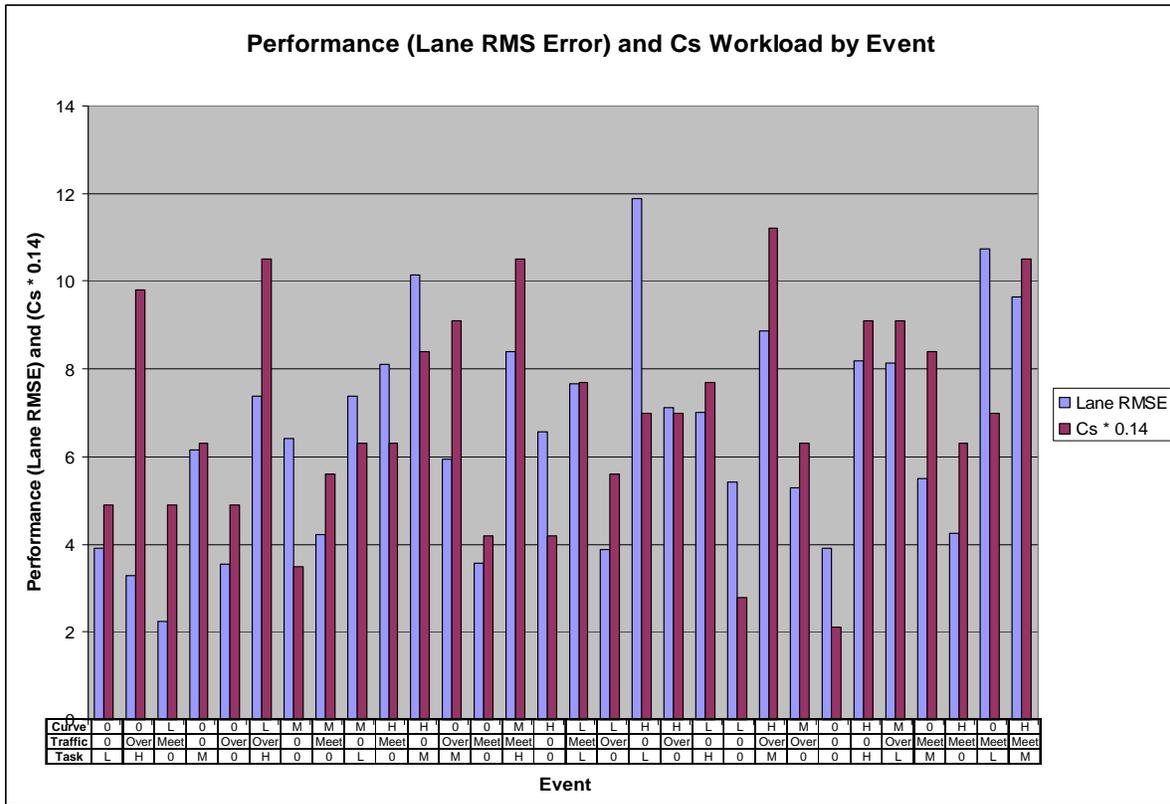


Figure 40: Performance and Cognitive Spatial Workload by Event

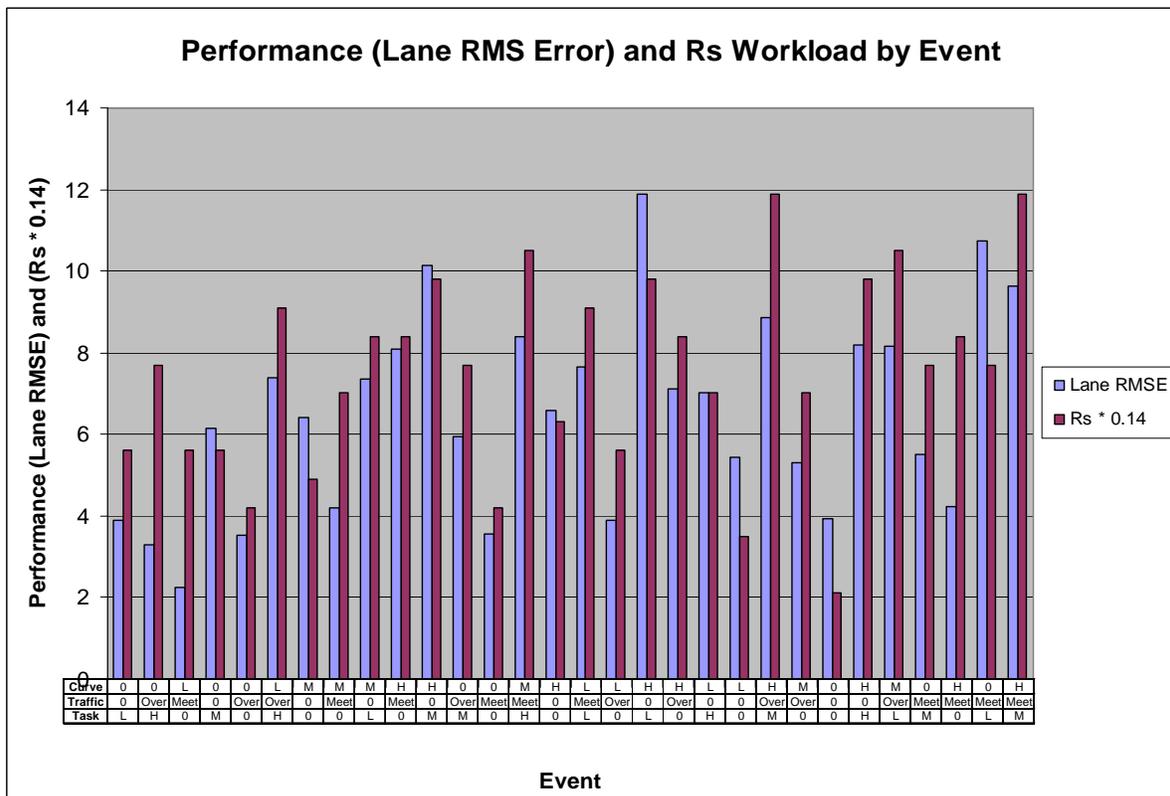


Figure 41: Performance and Response Spatial Workload by Event

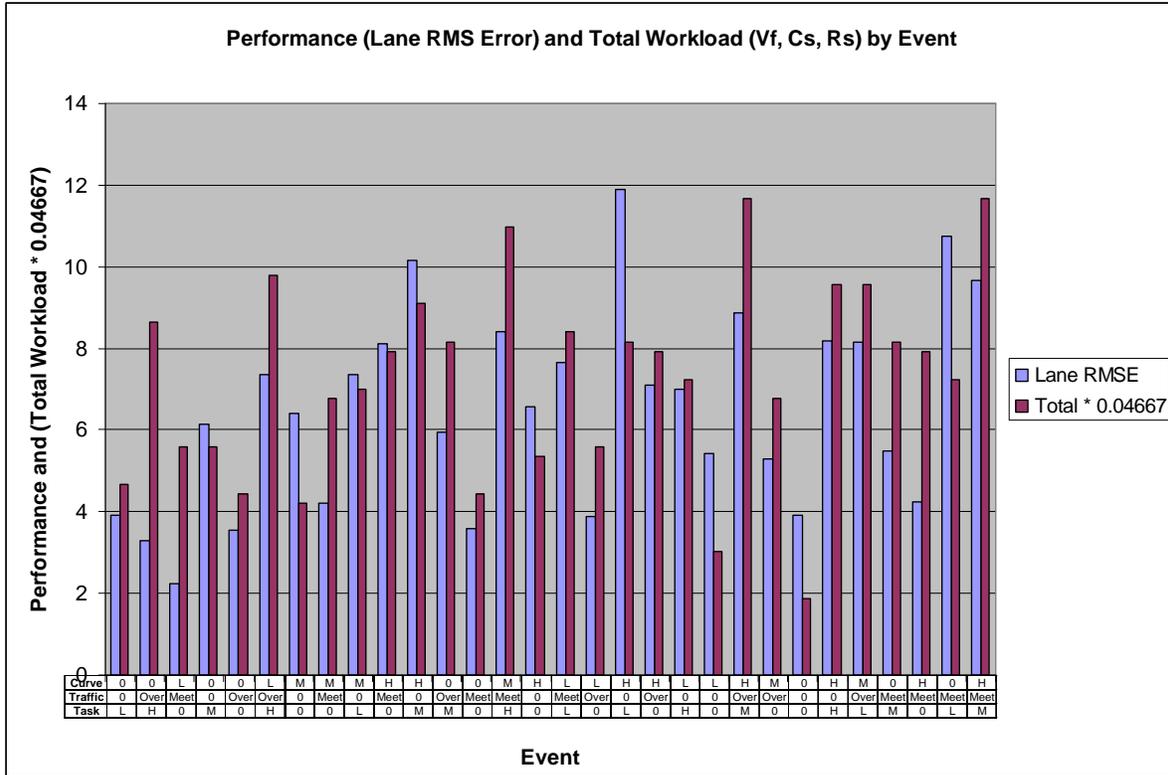


Figure 42: Performance and Total Workload by Event

As can be seen in Figures 39, 40, 41, and 42, the blue columns represent the recorded means for performance (lane RMS error), while the red columns represent the scaled workload values. For events where the blue column was taller than the red column, workload was underestimated, and similarly, for events where the red column was taller than the blue column, workload was overestimated as compared to the lane RMS error measure of performance.

4.5.4 Comparison Between Answer Times and Workloads

The following graphs (Figures 43 through 46) show the event-wise comparison of performance in terms of answer times and the scaled values for visual focal, cognitive spatial, and response spatial workload as well as for the sum of these three workloads.

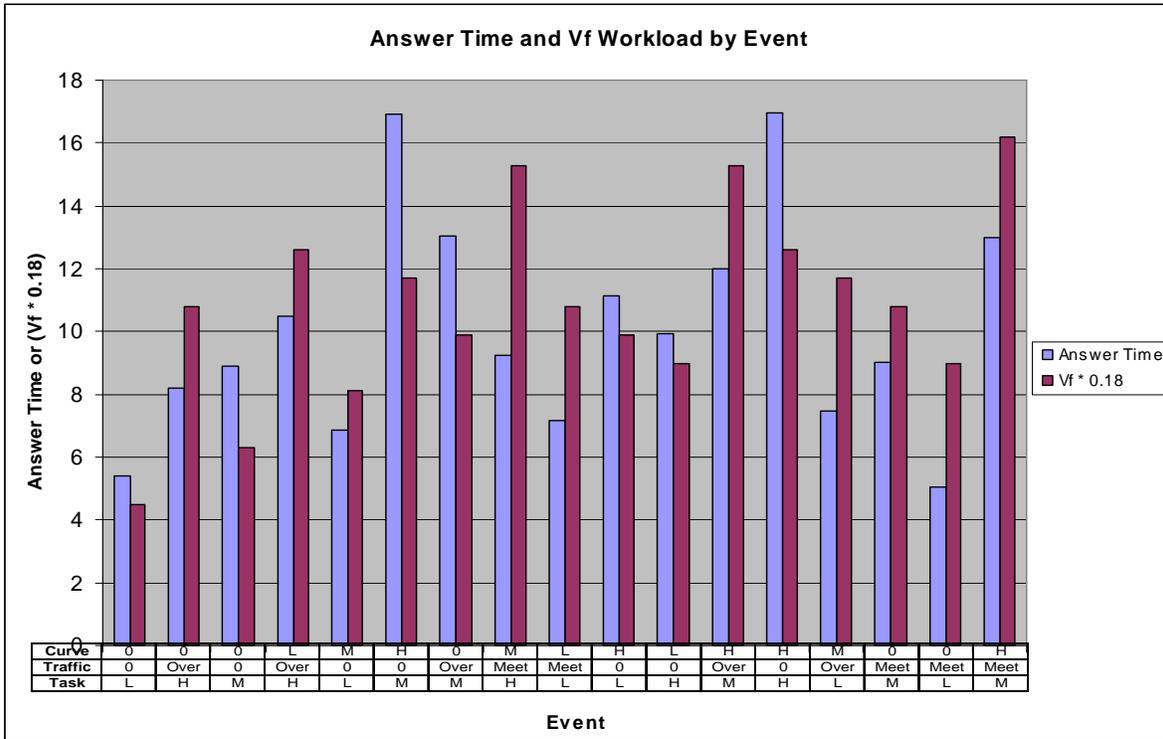


Figure 43: Answer Time and Visual Focal Workload by Event

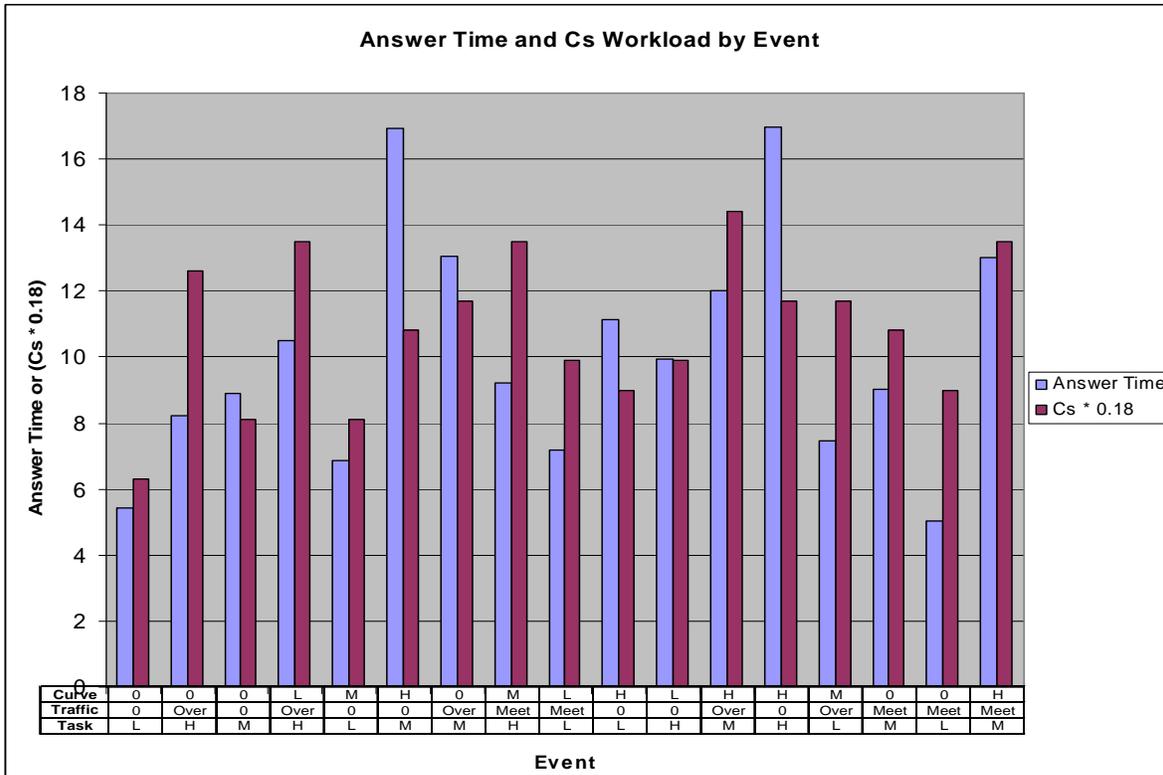


Figure 44: Answer Time and Cognitive Spatial Workload by Event

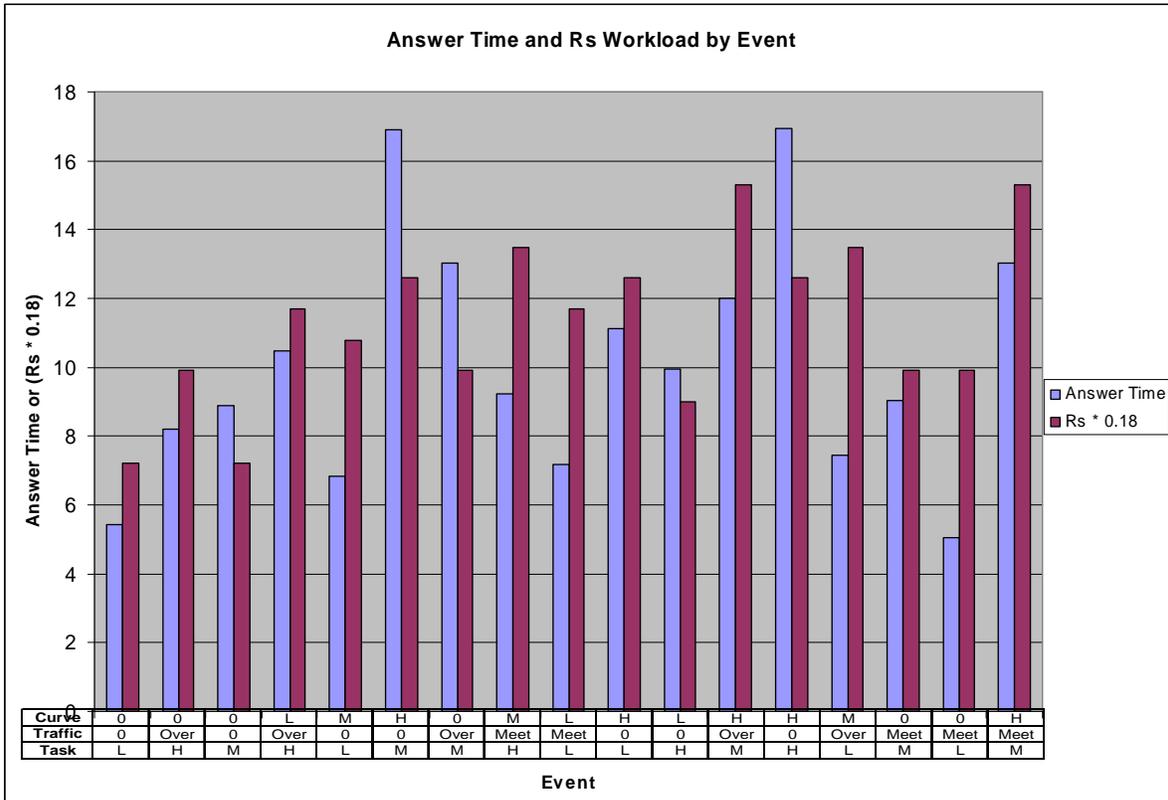


Figure 45: Answer Time and Response Spatial Workload by Event

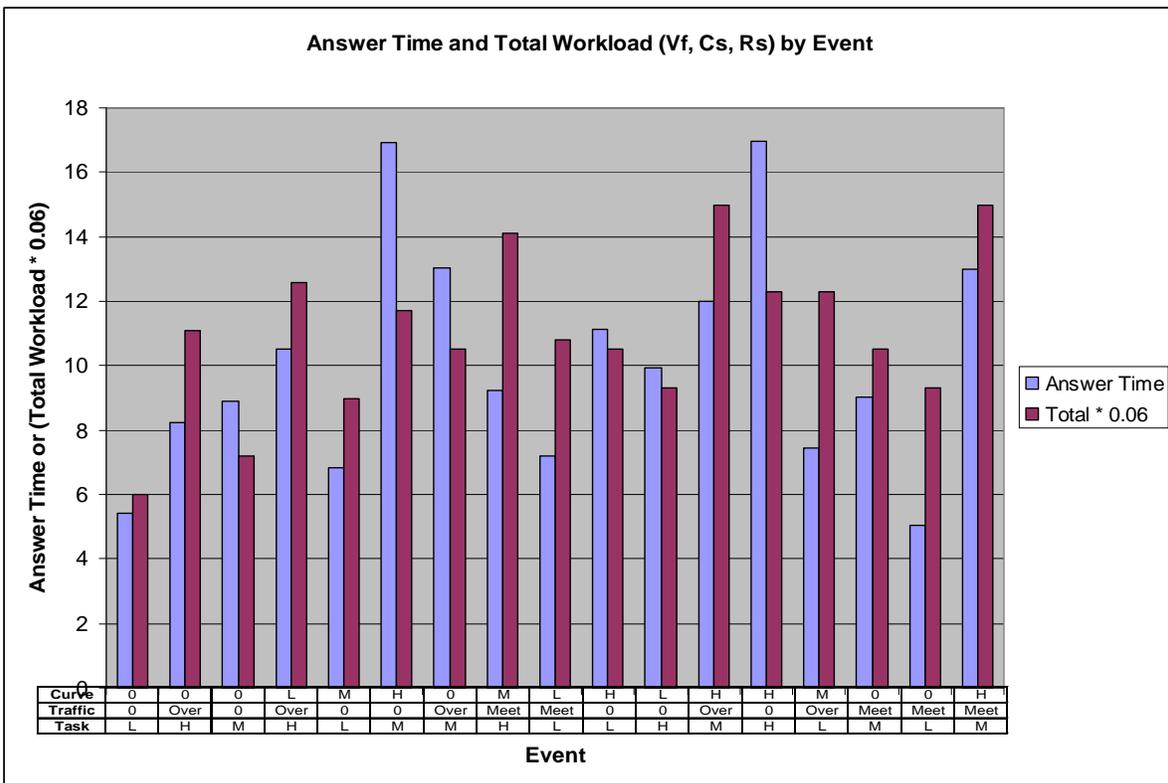


Figure 46: Answer Time and Total Workload by Event

Again, in Figures 43, 44, 45, and 46, the blue columns represent the recorded mean answer times, while the red columns represent the scaled workload values. For events where the blue column was taller than the red column, workload was underestimated, and similarly, for events where the red column was taller than the blue column, workload was overestimated as compared to the answer time metric.

4.5.5 Workload Adjustments

Using the data from the graphs comparing the total workload to the performance metric (Figures 42 and 46), three matrices were constructed. The values in the cells of these matrices represent the amount that should be added or subtracted from the total workload for each combination of curvature and task in order for the workload to mirror the performance measure. See Tables 17, 18, and 19 for these matrices.

Table 17: Amount to Adjust Workload Based on Performance with No Task

		Amount to Adjust Total Workload (Vf, Cs, Rs)				
		Based on Performance (Lane RMSE) with No Navigation Task				
		Traffic	None	Over	Meet	Average
Curve	Straight	43.950	-19.173	-18.416	2.120	
	Low	51.208	-36.591	-72.097	-19.160	
	Med	47.260	-31.594	-54.729	-13.021	
	High	25.811	-17.727	-37.753	-9.890	
	Average	42.057	-26.271	-45.749	-9.988	

Table 18: Amount to Adjust Workload Based on Performance with Task

		Amount to Adjust Total Workload (Vf, Cs, Rs)				
		Based on Performance (Lane RMSE) with Navigation Task				
		Traffic	None	Over	Meet	Average
Curve	Straight	-2.376	-81.167	8.880	-24.888	
	Low	-4.729	-52.053	-15.794	-24.192	
	Med	7.891	-30.420	-54.880	-25.803	
	High	24.203	-60.099	-43.290	-26.395	
	Average	6.247	-55.935	-26.271	-25.319	

Table 19: Amount to Adjust Workload Based on Answer Time Metric with Task

		Amount to Adjust Total Workload (Vf, Cs, Rs)				
		Based on Answer Time with Navigation Task				
		Traffic	None	Over	Meet	Average
Curve	Straight		9.308	-2.852	-47.736	-13.760
	Low		10.545	-35.023	-60.280	-28.253
	Med		-35.888	-80.641	-81.071	-65.866
	High		58.289	-49.779	-33.163	-8.218
	Average		10.564	-42.074	-55.563	-29.024

4.6 Conclusions from the Analyses

In the analyses of variance for both the lane RMS error and answer times, road curvature was significant. According to the lane RMS error method, only low curvature and straight roads did not show statistically significant differences in means. There also appeared to be an upward trend in lane RMS error values as the road curvature increased. Using the answer time means, medium curvature roadways and straight roads were not significantly different. This observation could be due to drivers accommodating for the increase in curvature by concentrating harder, thus lowering their effective workload. An accommodation of this type may not have occurred for low curvature roads, and high curvature roads may have posed too much of a challenge for drivers to fully accommodate the increase in workload.

For both analyses of variance, task difficulty was also significant. In the lane RMS error analysis, low and medium difficulty tasks were not significantly different. For the answer time analysis, all tasks were significantly different; however, the mean for medium difficulty tasks was larger than the mean for high difficulty tasks. This observation could mean that the visual search element of any of the tasks was much more demanding than the cognitive component of the high difficulty task. Because the trend for lane RMS error's measurement of performance seemed to indicate that the classifications of low, medium, and high difficulty did not accurately predict performance for those tasks (the trend decreased instead of increasing), the task types were divided into just two categories, no task and task, in later analysis of adjusted workloads.

Traffic type was not significant in the lane RMS error ANOVA but was for the answer time ANOVA. All traffic types were significantly different with the answer time analysis, but the mean answer time actually decreased as traffic was added to an event. This could be an indicator that subjects focused more on staying in the center of the lane as they encountered other vehicles than when no traffic was present.

The interaction of curvature and traffic type was not significant in the lane RMS error ANOVA but was for the answer time ANOVA. For drivers on roads with low, medium, or high curvature, the trend of mean performance (lane RMS error) seemed to signify that drivers became more focused on staying in the center of their lane as they encountered other

vehicles for all road curvatures. The curvature and task interaction was significant for both analyses of variance, and traffic type and task difficulty interactions were only significant for the lane RMS error ANOVA.

When comparing predicted workload to the lane RMS error performance measure, the simple linear regression between response spatial resources and performance had the highest R-Square value (R-Sq = 50.1%, $p = 0.000$), while the second highest simple linear regression used the sum of visual focal, cognitive spatial, and response spatial resources (R-Sq = 36.5%, $p = 0.000$). The multiple linear regression for lane RMS error which accounted for the greatest amount of the variance in performance was the regression using visual focal, cognitive spatial, cognitive verbal, and response spatial resources (R-Sq = 66.3%, $p = 0.000$). When a step-wise regression was performed on the individual data points as opposed to the means, the best fit model incorporated response spatial and visual focal resources (R-Sq = 21.28%, $p < 0.0001$).

The simple linear regression for answer times which accounted for the highest percentage of the variance used the sum of visual focal, cognitive spatial, and response spatial resources (R-Sq = 25.4%, $p = 0.039$). The second-best simple linear regression contained only visual focal workload (R-Sq = 25.2%, $p = 0.040$). The multiple linear regression for answer time with the highest R-Square value contained visual focal, cognitive spatial, and response spatial workloads (R-Sq = 25.4%, $p = 0.267$); however, neither of the multiple linear regressions on answer time were significant. Finally, the step-wise regression on individual data points found the best model to contain visual focal workload and the maximum workload in any category (R-Sq = 14.66%, $p < 0.0001$), although because the total workload (Vf + Cs + Rs) accounted for 13.07% of the variance by itself, the step-wise regression using this total and the maximum of the three workloads must be considered (R-Sq = 14.33%, $p < 0.0001$).

The correlation between the two performance measures (lane RMS error and answer time) in this experiment was low; two reasons for this low correlation could be that one (or both) of the performance measures were not sensitive to changes in workload or that one (or both) of the performance measures did not actually measure or correspond to workload. By adjusting the total workload by the amounts recommended in Tables 17, 18, and 19, the data could be analyzed again. If the resulting regression models account for significantly higher amounts of variance when using the new workload values, the demand matrix should be modified and validated for future use. If the regression models formed from the new workloads make little or no improvements over the current regressions, a method to further eliminate the individual differences between subjects or a more sensitive model of workload is recommended.

5 DISCUSSION

The issue of evaluating and controlling the amount of mental workload in commercial truck drivers is gaining interest due the increased number of in-vehicle information, entertainment and communication systems that are being placed in the cabs. There is a concern that some of these systems might increase the driver's mental workload when driving, subsequently increasing the risk of both single and multiple vehicle accidents.

Another emerging technology that has the potential to significantly alter the commercial truck driver's mental workload is the use of active safety devices (lane departure warnings, adaptive cruise control, collision avoidance systems, etc.). One of the obvious purposes of these systems is to reduce the risk of accidents by warning the driver of potential dangers or even taking some amount of control of the vehicle from the driver to avoid the risk. User acceptance is an important component of the effective implementation of active safety devices. To the extent that they are perceived as increasing the driver's workload (e.g., due to false alarms) acceptance by the users will be low. The issue is that the same warning that is perceived to be a false alarm to one person can be an important alert that avoids an accident for a different person. Another issue relates to whether the active safety devices become a crutch in the context of the theory of "risk homeostasis" (Wilde, 1994. 2001). Risk homeostasis theory describes the phenomenon of people modifying their behavior to accept a certain risk, even when safety devices are provided. For example, there is evidence that commercial truck drivers sometimes have a tendency to drive for longer durations, even if they are more tired, when there are rumble strips on the shoulder of the road. If the active safety devices lead drivers to pay "less" attention to the primary driving tasks due to the benefits of the active safety devices (e.g., collision avoidance systems) , safety could actually be reduced.

The objective of the computer simulation model of driver workload was to provide a method of evaluating the negative aspects of distractions while driving, in combination with the positive benefits of active safety devices. The multiple resource model structure worked well to characterize the perceptual, cognitive and response requirements of the driving task. The validation portion study indicated that some of the initial hypotheses were supported, while others were not. The primary issue that limits the utility of such a model is the ability to establish accurate workload values that are associated with various activities. The results indicate the long understood fact that there are large individual differences among people. In addition, the current model assumed additively of workload in that when two things are occurring simultaneously, the workload was assumed to be the sum of the two conditions. However, the interaction or interference effects might be very non-linear.

In summary, the computer simulation model can be used to evaluate safety implications of distractions, as well as active safety systems. In particular, the model can be used to evaluate the relative workload of two, competing systems. The relative performance using one system versus another (e.g., using different modalities) is more easily assessed and validated than is the fact that one or either of the systems changes the safety risk in an absolute sense.

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APPENDIX A: The Demand Matrix

Tasks	Workloads					
	Perceptual		Cognitive		Response	
	Vf	Af	Cs	Cv	Rs	Rv
Lane Keeping_Straight	10	0	15	0	15	0
Lane Keeping_Curvature_Low	20	0	20	0	25	0
Lane Keeping_Curvature_Med	30	0	25	0	35	0
Lane Keeping_Curvature_High	40	0	30	0	45	0
2_Lane_One_Car_Meeting	25	0	15	0	15	0
2_Lane_Multiple_Cars_Meeting	35	0	15	0	20	0
2_Lane_One_Car_Overtaking	20	0	20	0	15	0
2_Lane_Multiple_Cars_Overtaking	25	0	25	0	20	0
4_Lane_One_Car_Overtaking	10	0	15	0	5	0
4_Lane_Multiple_Cars_Overtaking	15	0	20	0	5	0
2_Lane_Passing_1_Mirror/Window_Check	60	0	45	0	10	0
2_Lane_Passing_1_Lane_Change	40	0	60	0	50	0
2_Lane_Passing_1_Return_Check	60	0	30	0	10	0
2_Lane_Passing_1_Return	20	0	50	0	40	0
2_Lane_Passing_2_Mirror/Window_Check	65	0	55	0	10	0
2_Lane_Passing_2_Lane_Change	40	0	65	0	70	0
2_Lane_Passing_2_Return_Check	60	0	30	0	10	0
2_Lane_Passing_2_Return	20	0	50	0	40	0
4_Lane_Passing_1_Mirror/Window_Check	40	0	25	0	10	0
4_Lane_Passing_1_Lane_Change	0	0	40	0	45	0
4_Lane_Passing_1_Return_Check	40	0	20	0	10	0
4_Lane_Passing_1_Return	0	0	30	0	40	0
4_Lane_Passing_2_Mirror/Window_Check	45	0	35	0	10	0
4_Lane_Passing_2_Lane_Change	0	0	40	0	45	0
4_Lane_Passing_2_Return_Check	45	0	20	0	10	0
4_Lane_Passing_2_Return	0	0	30	0	40	0
In-Vehicle Tasks	Vf	Af	Cs	Cv	Rs	Rv
Navigation_Low_Difficulty	15	0	20	80	25	0
Navigation_Med_Difficulty	25	0	30	80	25	0
Navigation_High_Difficulty	30	0	35	80	25	0
Search_Task	40	0	20	0	40	0
Phone_Ring	0	30	15	0	0	0
Phone_Pickup	20	45	15	0	20	0
Phone_Caller_ID_Check	25	0	0	80	0	0
Phone_Answer	10	0	10	0	10	0
Phone_Conversation	0	80	10	80	15	80
Phone_Replace	10	0	10	0	25	0
Hands_Free_Caller_ID_Check	80	0	0	80	0	0
Hands_Free_Phone_Answer	10	0	10	0	10	0
Hands_Free_Phone_Conversation	0	80	0	80	0	80
Hands_Free_Phone_Hangup	10	0	5	0	10	0
Navigation_Screen_Read_HDD	80	0	45	80	0	0
Navigation_Verbal_Message	0	80	0	80	0	0
Navigation_Manual_Control	20	0	30	0	70	0
Navigation_Verbal_Control	5	80	0	80	15	80
Radio_Start_Change	15	50	20	45	30	0
Radio_Listening	0	40	0	25	0	0
Heating_Air_Start_Change	15	0	20	0	30	0
Voice_Rec_Heating_Air_Change	10	80	0	80	0	80
Adaptive_Cruise_Control_Automatic	Vf	Af	Cs	Cv	Rs	Rv
0-2_Car_Length_Separation	0	0	0	0	0	0
3-10_Car_Length_Separation	-15	0	-15	0	-15	0
11-15_Car_Length_Separation	-10	0	-10	0	-10	0
16-20_Car_Length_Separation	0	0	0	0	0	0
Collision_Avoidance_Auditory	-10	20	-5	0	-5	0
Collision_Avoidance_Visual	-5	0	-5	0	-5	0
Collision_Avoidance_Haptic	-10	0	-5	0	-5	0
External_Factors	Vf	Af	Cs	Cv	Rs	Rv
Light_Rain	10	0	5	0	5	0
Heavy_Rain	25	0	10	0	30	0
Ice_Or_Sleet	25	0	25	0	40	0
Snow	30	0	25	0	40	0
Light_Wind	0	0	15	0	20	0
Heavy_Wind	0	0	20	0	35	0
Sun_In_The_Eyes	40	0	25	0	35	0
Sign-Reading	15	0	10	25	0	0
Animal_Obstacle	50	0	55	0	60	0
Siren	15	80	20	0	15	0

APPENDIX B: Consent Forms for Subjects

INFORMED CONSENT FORM FOR VOLUNTEERS

Title: *Driver Workload Demand Model Validation in a Simulated Driving Task*

Researchers: Meredith Griffin, Industrial Engineering Undergraduate, University of Arkansas
Dr. Steve Johnson, Professor of Industrial Engineering, University of Arkansas

Introduction: We are conducting research pertaining to the effects of multiple driving tasks on mental workload. You will be asked to answer background questions about your vision and driving capabilities before the experiment and then will complete two driving scenarios on the driving simulator. The first will be a practice run that lasts about ten minutes, and the second will be an approximately twenty-minute scenario. During these scenarios, you will also answer questions using the keypad to your right about maps presented to you on the second monitor. After the driving scenarios, you will fill out a brief questionnaire about the experience.

Risks: A small percentage of participants in this experiment may experience simulator motion sickness. If you begin to experience any discomfort, inform the experimenter. The session will be terminated immediately with no negative consequences to you. There are no other known risks to your participation in this experiment.

Benefits: This study will provide useful data to aid in the validation of our model of driver workload demand.

Duration: This experiment generally lasts 45-60 minutes.

Confidentiality: All data obtained in the study will be confidential and any information about you will be kept private. Your name will not be associated with your data at any point in time.

Right to Ask Questions: During the experiment, you are free to ask any questions about the research.

Voluntary Participation/Withdrawal: Your participation in this experiment is voluntary and you can refuse to be in this study or drop out at any time, with no negative consequences.

Contact Persons: This study is being conducted by the University of Arkansas. If you have any questions or concerns about your rights as a participant in this research study, you may contact Steve Johnson at (479) 575-6034.

If you voluntarily agree to participate in this study, please sign your name and enter the date on the lines below.

_____	_____
Participant Signature	Date
_____	_____
Principal Investigator	Date

INFORMED CONSENT FORM FOR CLASS PARTICIPANTS

Title: *Driver Workload Demand Model Validation in a Simulated Driving Task*

Researchers: Meredith Griffin, Industrial Engineering Undergraduate, University of Arkansas
Dr. Steve Johnson, Professor of Industrial Engineering, University of Arkansas

Introduction: We are conducting research pertaining to the effects of multiple driving tasks on mental workload. You will be asked to answer background questions about your vision and driving capabilities before the experiment and then will complete two driving scenarios on the driving simulator. The first will be a practice run that lasts about ten minutes, and the second will be an approximately twenty-minute scenario. During these scenarios, you will also answer questions using the keypad to your right about maps presented to you on the second monitor. After the driving scenarios, you will fill out a brief questionnaire about the experience.

Risks: A small percentage of participants in this experiment may experience simulator motion sickness. If you begin to experience any discomfort, inform the experimenter. The session will be terminated immediately with no negative consequences to you. There are no other known risks to your participation in this experiment.

Benefits: This study will provide useful data to aid in the validation of our model of driver workload demand.

Duration: This experiment generally lasts 45-60 minutes.

Confidentiality: All data obtained in the study will be confidential and any information about you will be kept private. Your name will not be associated with your data at any point in time.

Right to Ask Questions: During the experiment, you are free to ask any questions about the research.

Voluntary Participation/Withdrawal: Your participation in this experiment is voluntary and you can refuse to be in this study or drop out at any time, with no negative consequences. If you agree to participate in this experiment, you will receive credit for your participation in either INEG 3713 Methods and Standards or INEG 4723 Ergonomics.

Contact Persons: This study is being conducted by the University of Arkansas. If you have any questions or concerns about your rights as a participant in this research study, you may contact Steve Johnson at (479) 575-6034.

If you voluntarily agree to participate in this study, please sign your name and enter the date on the lines below.

Participant Signature	Date
Principal Investigator	Date

APPENDIX C: Pre-Experimental Questionnaire

PRE-EXPERIMENTAL QUESTIONNAIRE

1. Age: _____
2. Sex: Male Female
3. Handedness: Right Left
4. Health: (worst) 1 2 3 4 5 (best)
5. Do you wear glasses or contacts on a regular basis? No Yes
6. Are you color blind? No Yes
7. Have you ever driven in a driving simulator before? No Yes
8. How many miles do you drive annually? _____
9. How many years of driving experience do you have? _____
10. How many trips per year do you drive more than 500 miles at a time? _____
11. What is your occupation? _____
12. What is your nationality? _____

APPENDIX D: Distraction Task Practice Sheets

DISTRACTION TASK PRACTICE SHEET

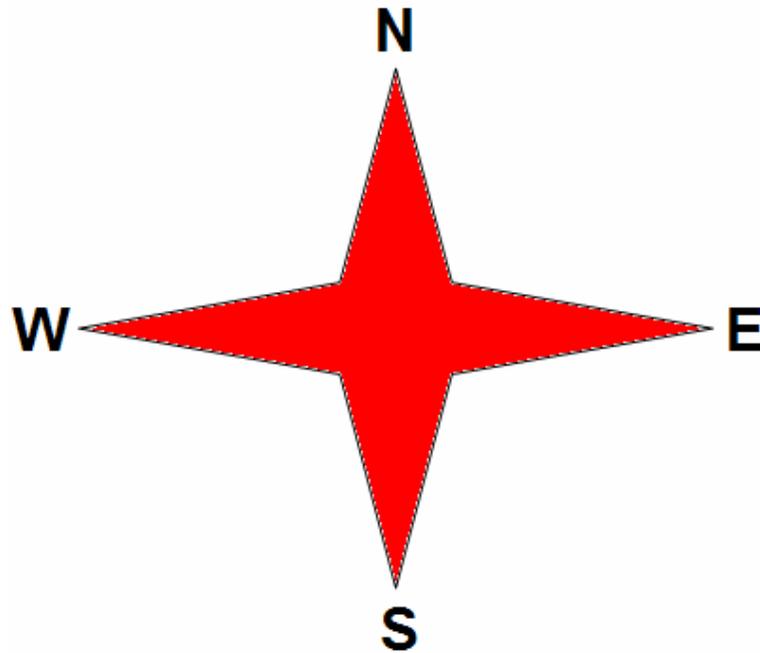
Map 1

What is the next right turn?

- 1. Carson St.
- 2. Belgrade St.
- 3. Belgrade Factory Dr.
- 4. Rafnell St.



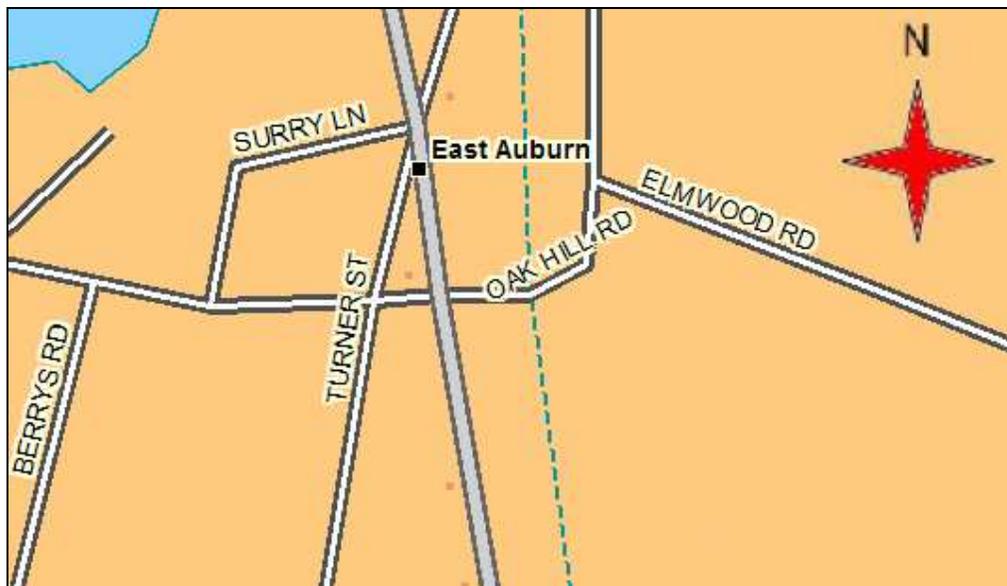
Compass



Map 2

Berrys Rd. is _____ of Turner St.

- 1. North
- 2. South
- 3. East
- 4. West



Map 3

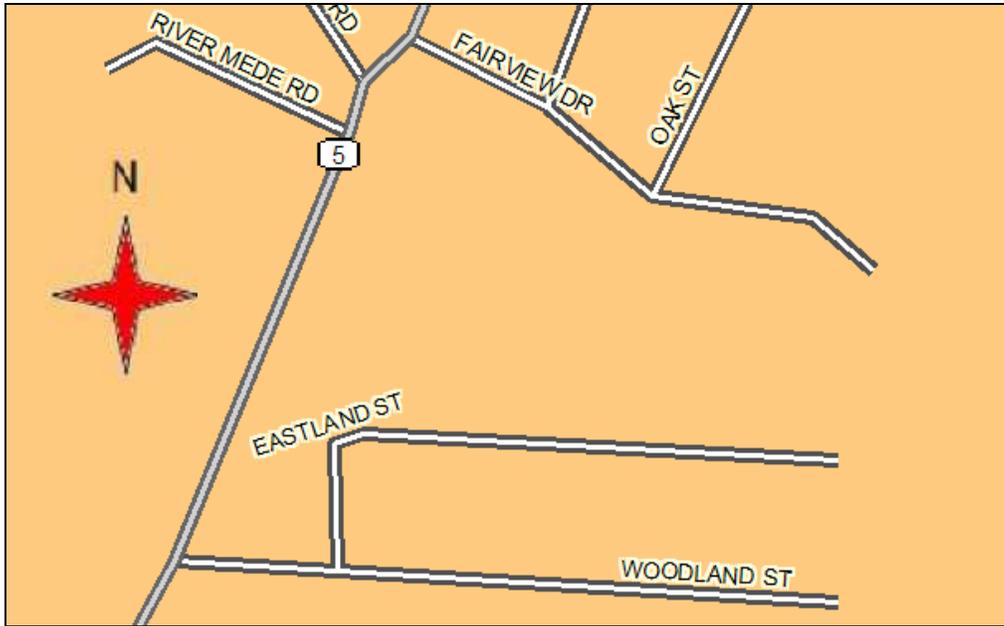
Eastland St. is _____ of Woodland St.

North

$25 - 4 = ?$

South

$28 - 3 = ?$



Map 4

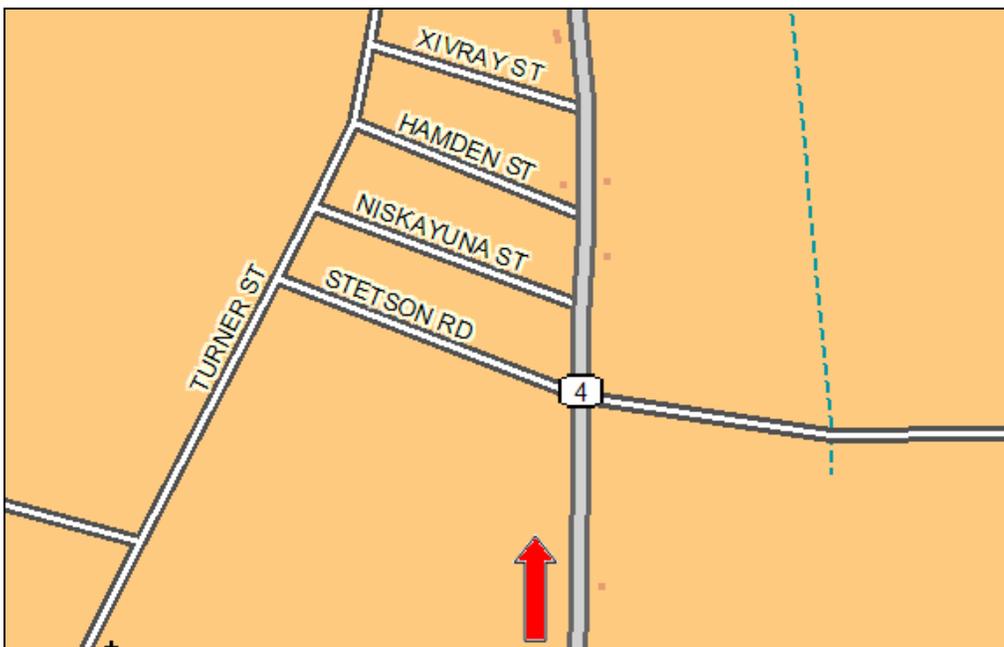
Turn _____ for Hamden St.

Left

$16 + 3 = ?$

Right

$15 + 2 = ?$



APPENDIX E: Experimental Protocol

EXPERIMENTAL PROTOCOL

1. Start the *STISIM Drive* program.
2. Load the file *DO-SimulationConfiguration.Cfg*.
3. Select the file *Simulation PILOT (3.14.07).Evt* in the Scenario or Project File field.
4. Type *StisimResult.txt* in the Output Data File Name field.

Turn on the computer speakers.

Seat participant in the chair in front of the steering wheel.

Are you a student in Ergonomics or Methods and Standards?

This is a consent form that discusses our study and says that you have the right to withdraw from the experiment at any time with no negative consequences. Please sign the form if you agree to participate.

Provide participant with the APPROPRIATE informed consent form.

Thank you very much for participating in this study. It should take you approximately 45 minutes to complete. This study will require you to drive in a driving simulator. In the past, some participants have felt uneasy after participating in studies using a simulator. To help identify people who might be prone to this feeling, we would like to ask you the following questions.

Fill in responses on Participant Response Worksheet.

- Do you (or have you had) a history of migraine headaches? claustrophobia? or motion sickness?
- Do you (or have you had) a history of any health problems like seizures, diabetes, heart problems, or vertigo that may affect your ability to drive?
- Are you currently taking any medications that may affect your ability to drive?
- (Females Only) Are you (or is there a possibility) that you might be pregnant?

During this experiment, if you feel sick at any time, please let me know.

Give subjects pre-experimental questionnaire.

Before we begin, please fill out this pre-experimental questionnaire. The questionnaire will give us a history of your driving experience.

We are now ready to begin. In order to make yourself familiar with the simulator, we will ask you to do a 10-minute practice drive. During this time, you will become familiar with the steering, acceleration, and braking of the driving simulator. This first drive consists of curved and straight sections of a rural two-lane highway with a 55 mph speed limit. You will also encounter other vehicles on the road. We are trying to gauge your level of workload while driving, so although this is a practice scenario, it is important that you operate the vehicle as you normally would to ensure safe driving.

You will also be asked to perform secondary tasks in addition to the primary driving task. All of the secondary tasks will be presented on the second computer monitor to your right. The tasks will consist of a map and a question about that map. You should answer the question using the keypad on your right. You will be signaled to start a secondary task when you hear the sound I will play for you now.

*Play the C:\STISIM\SOUND\SOUND136.wav sound file.
Plug in and turn on the headphones.*

After you have entered your response to the question, the map will disappear until the next task. It is important that you do not leave your right hand on the keypad during the run. Your right hand should be either on the steering wheel or in your lap, whichever you prefer, until it is time for you to respond to the question.

Give participant distraction task practice sheet.

This sheet shows the three types of tasks you will have to perform while driving.

The first type of task (see map 1) will ask you the question “What is the next left turn?” or “What is the next right turn?” The red arrow on this map will show you where your car is and which direction you are heading. You should choose the correct response from the four answer choices, enter that number on the keypad, and press ENTER. It is important that you press ENTER after you answer any question.

For the map 1, what would you answer on the keypad?

Correct answer is (2. Belgrade St). Remind them to press ENTER after their response.

Do you have any questions about the first type of task?

The second type of task requires that you know the four cardinal directions. Look at the compass printed on the practice sheet. The top point of the compass points North, the bottom points South, the left points West, and the right points East. These are the directions we will use on the second type of map. The map will have a red compass pointing North on it and will ask you to determine the relationship between two roads, for example, the sentence could say “Road X is ___(Blank)___ of Road Y.” You would then have to find Road X and Road Y on the map, determine if Road X is north, south, east, or west of Road Y, input your answer on the keypad, and press ENTER.

For the map labeled (2), what would you answer on the keypad?

Correct answer is (4. West). Remind them to press ENTER after their response.

Do you have any questions about the second type of task?

The third type of task (see maps 3 and 4) will be like the first two, except you will be required to do an elementary math problem as well. This task will have only two answer choices. In map 3, for example, there is a compass pointing north with the sentence “Eastland St. is __(Blank)__ of Woodland St.,” and the answer choices are North and South. You will have to choose the correct answer and then solve the math problem below the answer you chose. The answer to the math problem is what you should type on the keypad.

So, for the map labeled (3), what would you answer on the keypad?

Correct answer is (North: $25-4=21$). Remind them to press ENTER after their response.

This type of task may also have a red arrow on it, showing your location and direction, and may say “Turn __(Blank)__ for Road X.” In this case the answer choices will be Left and Right. Again, you should choose the correct answer and then solve the math problem below the answer you chose. The answer to the math problem is what you should type on the keypad.

So, for the map labeled (4), what would you answer on the keypad?

Correct answer is (Left: $16+3=19$). Remind them to press ENTER after their response.

Do you have any questions about the third type of task?

Please remember that there will be curves during this drive, so you should slow down as much as you normally would before you enter the curves. Some people have tried to answer the secondary task questions as soon as they appear and subsequently have driven the car off the road and crashed. Remember that you should drive as you would in a real-life situation; the most important thing is that you do not crash while driving the simulator. Also, remember that the sound I played for you means there is a new task to be performed on the second monitor.

After this practice drive, there will be a short break. Then we will start the official run. Do you have any questions before we begin?

We ask that you wear these headphones to eliminate any distracting noises in the room. Please put them on now.

- 1. Start the program PracticeRecordDriverTimer.exe on the navigation computer.*
- 2. Start the STISIM program, ensuring that the box called Create file name from driver information is NOT checked.*
- 3. After the run, join the generated files by starting the programs PracticeSerialReceiveData.exe and SerialSendData.exe. Press Receive and Send and check that the result file has been generated in the Practice folder.*

Before we continue, do you feel dizzy or nauseous? Or would you like to make any adjustments or stop the experiment now for any reason?

1. Select the file DO-Simulation (04.02.07).Evt in the Scenario or Project File field.
2. Check that the Output Data File Name field says StisimResult.txt and that the configuration file is DO-SimulationConfiguration.Cfg.

During the second drive, you will again be asked to perform secondary tasks in addition to the primary driving task. Remember to operate the vehicle as you normally would to ensure safe driving, while at the same time performing the secondary tasks to the best of your ability. The second drive will be similar to the practice scenario, but it will last approximately 15 minutes. Are you ready to begin?

1. Start the program RealDriverTimer.exe on the navigation computer.
2. Start the STISIM program, ensuring that the box called Create file name from driver information is **NOT** checked.

After the drive, provide the participant with the Post-Experimental Questionnaire.

Thank you for participating today. Before you leave, please take a moment to fill out the post-experimental questionnaire. Your responses on this questionnaire will help us improve the study in the future.

When the participant leaves, thank them for their time.

1. Save the StisimResult.txt file in the StisimResult Runs folder on the Desktop under the name Real.StisimResultPilot#.
2. Save the DriverTimer# file in the FinalReport > Real folder on the Desktop under the name #_RealDrvTimerPilot#.
3. Save the practice run file from the FinalReport > Practice folder on the Desktop under the name #_PracFinalReport.Pilot#.

APPENDIX F: Post-Experimental Questionnaire

POST-EXPERIMENTAL QUESTIONNAIRE

Please circle your responses.

1. How accurate was the simulation experience compared to an actual driving experience?

1 Not accurate 2 3 Moderately accurate 4 5 Very accurate

2. How accurate was the response from the gas and brake pedals?

1 Not accurate 2 3 Moderately accurate 4 5 Very accurate

3. How accurate was the steering?

1 Not accurate 2 3 Moderately accurate 4 5 Very accurate

4. How accurate was the view of the road and other cars?

1 Not accurate 2 3 Moderately accurate 4 5 Very accurate

5. How difficult was it for you to stay away from the right edge of the road?

1 Not difficult 2 3 Moderately difficult 4 5 Very difficult

6. How difficult was it for you to stay away from the center line?

1 Not difficult 2 3 Moderately difficult 4 5 Very difficult

7. How difficult was it to avoid other vehicles?

1 Not difficult 2 3 Moderately difficult 4 5 Very difficult

8. How difficult was it to turn the steering wheel on a curve?

1 Not difficult 2 3 Moderately difficult 4 5 Very difficult

9. How difficult was it to answer the map questions?

1 Not difficult 2 3 Moderately difficult 4 5 Very difficult

10. How many accidents have you been involved in when you were the driver? _____

11. Have you ever had your license revoked? No Yes

12. Have you ever participated in a driver education program? No Yes

APPENDIX G: STISIM Practice Scenario Code

-1 Country Road-- Head On Collision
-1 by: George Park
-1 Practice Run Developed by: Meredith Griffin and Cari Bogulski

-1 road; 2 way, 2 lanes, plateau style road with ditches right and left.
0,ROAD,12,2,1,1,1,10,10,.5,.5, 300, -1,-1, -5,6,-5,6, -30,10,-30,10, 0,0,0,
C:\STISIM\Data\Textures\Grass01.Jpg,12, 0,0, C:\STISIM\Data\Textures\Grass04.Jpg,12
0,TREE, 200, 0,*1~18;-15;-4, 50,100,0
0,SIGN, 100, 100, C:\STISIM\Data\Signs\SP55MPH.3DS, 0, 0, 0

-1 0,LS,55,100

-1*****

-1 Straight Road

-1 Signal the beginning of the simulation
0, DO, 4095
50, DO, 0

-1 CALVIN is a DISTANCE BASE 10 feet increment

-1 Saving Info:

-1 1: Elapsed Time Since the beginning of the run

-1 6: Total longitudinal distance (feet)

-1 4: Driver's longitudinal velocity (feet/second)

-1 7: Driver's lateral lane position with respect to the roadway dividing line, positive to the right (feet).

-1

0, BSAV, 0, 10, CALVIN, 1, 6, 4, 7

-1 Meeting Event on Low Curve to the Left

500,C,1000,100,750,100,-.00080
1500,A,*1,1000,-6,19

-1 Meeting Event on Medium Curve to the Right

2350,SIGN,5,1000,0,0
2500,C,1000,100,750,100, .00160
3400,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
3450,DO, 4095
3500,DO, 0
3200,A,*1,1000,-6,24

-1 Low Curve to the Right
4300,C,1000,100,750,100, .00080

-1 Overtaking Event on High Curve to the Left
5850,SIGN,4,1000,0,0
6000,C,1000,100,750,100,-.00240
6800, V, /30, -250, *0, 1, 4, 3, /-12, *30, 2, -3, *0, /30, 2
7050,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
7100,DO, 4095
7150,DO, 0

-1 Medium Curve to the Left
7650,SIGN,4,1000,0,0
7800,C,1000,100,750,100,-.00160

-1 Meeting Event on High Curve to the Right
9750,SIGN,5,1000,0,0
9900,C,1000,100,750,100, .00240
10900,A,*1,1000,-6,45
11150,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
11200,DO, 4095
11250,DO, 0

-1 Overtaking Event on Low Curve to the Left
12400,C,1000,100,750,100,-.00080
13100,V, /30, -250, *0, 1, 11, 3, /-12, *30, 2, -3, *0, /30, 2

-1 Meeting Event on Low Curve to the Right
14000,C,1000,100,750,100, .00080
15000,A,*1,1000,-6,10
15250,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
15300,DO, 4095
15350,DO, 0

-1 Meeting Event on High Curve to the Left
16750,SIGN,4,1000,0,0
16900,C,1000,100,750,100,-.00240
17900,A,*1,1000,-6,45

-1 Meeting Event on Straight Road
18900,A,*1,1000,-6,33

-1 Overtaking Event on High Curve to the Right
21050,SIGN,5,1000,0,0
21200,C,1000,100,750,100, .00240
21900,V, /30, -250, *0, 1, 2, 3, /-12, *30, 2, -3, *0, /30, 2

-1 Navigation Event on Straight Road
23450,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
23500,DO, 4095
23550,DO, 0

-1 overtaking on right low curvature
24000,C,1000,100,750,100, .00080
24700,V, /30, -250, *0, 1, 43, 3, /-12, *30, 2, -3, *0, /30, 2
24950,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
25000,DO, 4095
25050,DO, 0

-1 single meeting on left medium curvature
26050,SIGN,4,1000,0,0
26100,C,1000,100,750,100, -.00160
27100,A,*1,1000,-6,24

-1 CURVATURE ADDED med to R overtaking
27850,SIGN,5,1000,0,0
28000,C,1000,100,750,100, .00160
28700,V, /30, -250, *0, 1, 7, 3, /-12, *30, 2, -3, *0, /30, 2

-1 Overtaking Straight Road
30500,V, /30, -250, *0, 1, 6, 3, /-12, *30, 2, -3, *0, /30, 2
30750,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
30800,DO, 4095
30850,DO, 0

-1 High curve Navigation
31800,SIGN,4,1000,0,0
32050,C,1000,100,750,100,-.00240
33150,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
33200,DO, 4095
33250,DO, 0

-1 0,CV,80.6666667,1
-1 7000,CV,58.6666667,1
-1 6950,CV,80.6666667,1
-1 10900,CV,58.6666667,1
-1 11850,CV,80.6666667,1

0,RMSB,0,Total mean score
35500,RMSE
35500, ES

APPENDIX H: STISIM Real Scenario Code

-1 Country Road-- Head On Collision
-1 by: George Park
-1 Real Run Developed by: Meredith Griffin and Cari Bogulski

-1 road; 2 way, 2 lanes, plateau style road with ditches right and left.

0,ROAD,12,2,1,3,1,10,10,.5,.5, 300, -1,-1, -5,6,-5,6, 60,20,-70,30, 0,0,0,
C:\STISIM\Data\Textures\Dirt08.Jpg,12,C:\STISIM\Data\Textures\Grass06.Jpg,12

-0,ROAD,12,2,1,1,1,10,10,.5,.5, 300, -1,-1, -5,6,-5,6, -30,10,-30,10, 0,0,0, -
C:\STISIM\Data\Textures\Grass01.Jpg,12, 0,0, C:\STISIM\Data\Textures\Grass04.Jpg,12

0,TREE, 250, 0,*1~18;-15;-4, 50,100,0
0, SIGN, 100, 100, C:\STISIM\Data\Signs\SP55MPH.3DS, 0, 0, 0
0,LS,55,100

-1 Signal the beginning of the simulation
0, DO, 4095
50, DO, 0

-1 CALVIN is a DISTANCE BASE 10 feet increment

-1 Saving Info:

-1 1: Elapsed Time Since the beginning of the run

-1 6: Total longitudinal distance (feet)

-1 4: Driver's longitudinal velocity (feet/second)

-1 7: Driver's lateral lane position with respect to the roadway dividing line, positive to the right (feet).

-1

0, BSAV, 0, 10, CALVIN, 1, 6, 4, 7

-1 Navigation 1 Signal

950,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
1000, DO, 4095
1050, DO, 0

-1 2

5550, PR,C:\STISIM\SOUND\SOUND136.wav,0,4
5600, DO, 4095
5650, DO, 0

-1 3

9550,PR,C:\STISIM\SOUND\SOUND136.wav,0,4

9600, DO, 4095
9650, DO, 0

-1 4
12950, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
13000, DO, 4095
13050, DO, 0

-1 5
18650, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
18700, DO, 4095
18750, DO, 0

-1 6
21450, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
21500, DO, 4095
21550, DO, 0

-1 7
25550, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
25600, DO, 4095
25650, DO, 0

-1 8
28650, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
28700, DO, 4095
28750, DO, 0

-1 9
31650, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
31700, DO, 4095
31750, DO, 0

-1 10
35450, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
35500, DO, 4095
35550, DO, 0

-1 11
40150, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
40200, DO, 4095
40250, DO, 0

-1 12
43650, PR, C:\STISIM\SOUND\SOUND136.wav, 0, 4
43700, DO, 4095
43750, DO, 0

-1 13

49550,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
49600, DO, 4095
49650, DO, 0

-1 14
53350,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
53400, DO, 4095
53450, DO, 0

-1 15
57750,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
57800, DO, 4095
57850, DO, 0

-1 16
60950,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
61000, DO, 4095
61050, DO, 0

-1 17
65550,PR,C:\STISIM\SOUND\SOUND136.wav,0,4
65600, DO, 4095
65650, DO, 0

-1 55 mph signs
1200,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
2300,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
7600,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
8950,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
11000,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
16000,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
17700,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
19100,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
22500,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0
25000,SIGN,100,1000,C:\STISIM\Data\Signs\SP55MPH.3DS,0

-1*****

-1 EVENT A: single meeting on straight road

2000,A,*1,1000,-6,30

-1 CURVATURE ADDED
3150,SIGN,5,1000,0,0
3300,C,1000,100,750,100, .00160

-1*****

-1 EVENT B: overtaking on straight road

5100,V,/30,-250,*0,1,4, 3,-12,*30,2,-3,*0,/30,2

-1 CURVATURE ADDED

6100,C,1000,100,750,100,.00080

-1*****

-1 EVENT C: single meeting on right low curvature

8500,A,*1,1000,-6,19

-1 CURVATURE ADDED

9300,C,1000,100,750,100,-.00080

-1*****

-1 EVENT C2: overtaking on straight road

11300,V,/30,-250,*0,1,2, 3,-12,*30,2,-3,*0,/30,2

-1*****

-1 EVENT D: overtaking on right low curvature

12500,V,/30,-250,*0,1,43, 3,-12,*30,2,-3,*0,/30,2

-1 CURVATURE ADDED

13850,SIGN,4,1000,0,0
14000,C,1000,100,750,100,-.00160

-1*****

-1 EVENT E: single meeting on left medium curvature

16500,A,*1,1000,-6,24

-1 CURVATURE ADDED

17250,SIGN,5,1000,0,0
17400,C,1000,100,750,100,.00160

-1*****

-1 EVENT F: single meeting on right high curvature

19400,A,90,1000,-6,21

-1*****

-1 Road curvature and signs

7500,C,1000,100,750,100,-.00080
11800,C,1000,100,750,100, .00080

15350,SIGN,4,1000,0,0
15500,C,1000,100,750,100,-.00160

18585,SIGN,5,1000,0,0
18600,C,1000,100,750,100, .00240

20350,SIGN,4,1000,0,0
20500,C,1000,100,750,100,-.00240

23350,SIGN,5,1000,0,0
23500,C,1000,100,750,100, .00160

-1*****

-1 EVENT G: single meeting on left high curvature

21500,A,*1,1000,-6,45

-1*****

-1 EVENT H: single meeting on right medium curvature

24500,A,*1,1000,-6,25

-1 CURVATURE ADDED

25350,SIGN,5,1000,0,0
25500,C,1000,100,750,100, .00240

-1*****

-1 EVENT I: single meeting event on straight road

27500,A,*1,1000,-6,6

-1*****

-1 EVENT J: overtaking on right medium curvature

28300, V, /30, -250, *0, 1, 18, 3, /-12, *30, 2, -3, *0, /30, 2

-1 CURVATURE ADDED

29100,SIGN,4,1000,0,0
29250,C,1000,100,750,100,-.00240

-1*****

-1 EVENT K: single meeting on left low curvature

31400,A,*1,1000,-6,39

-1 CURVATURE ADDED

32250,SIGN,4,1000,0,0

32400,C,1000,100,750,100,-.00160

-1*****

-1 EVENT L: overtaking on right low curvature

-34300,A,*1,1000,-6,

34300,V, /30, -250, *0, 1, 1, 3, /-12, *30, 2, -3, *0, /30, 2

-1 CURVE HIGH TO LEFT FIXED

34350,SIGN,4,1000,0,0

34500,C,1000,100,650,100,-.00240

-1 CURVATURE ADDED

35450,SIGN,5,1000,0,0

35600,C,1000,100,750,100, .00240

-1*****

-1 EVENT M: overtaking on left high curvature

37700,V, /30, -250, *0, 1, 27, 3, /-12, *30, 2, -3, *0, /30, 2

-1 CURVATURE ADDED

39000,C,1000,100,750,100, .00080

40500,C,1000,100,750,100,-.00080

-1*****

-1 Road curvature and signs

27350,SIGN,5,1000,0,0

27500,C,1000,100,750,100, .00160

30500,C,1000,100,750,100,-.00080

33500,C,1000,100,550,100, .00080

36750,SIGN,4,1000,0,0

37000,C,1000,100,750,100,-.00240

42350,SIGN,5,1000,0,0
42500,C,1000,100,750,100, .00240

45350,SIGN,4,1000,0,0
45500,C,1000,100,750,100,-.00160

-1*****

-1 EVENT N: overtaking on right high curvature

43200,V, /30, -250, *0, 1, 34, 3, /-12, *30, 2, -3, *0, /30, 2

-1 CURVATURE ADDED

44350,SIGN,5,1000,0,0
44500,C,1000,100,750,100, .00160

-1*****

-1 EVENT O: overtaking on left medium curvature

46200,V, /30, -250, *0, 1, 22, 3, /-12, *30, 2, -3, *0, /30, 2

-1 CURVATURE ADDED

48350,SIGN,5,1000,0,0
48500,C,1000,100,750,100, .00240

-1*****

-1 EVENT P: single meeting on right high curvature

49500,A,*1,1000,-6,2

-1*****

-1 EVENT P2: single meeting on a straight road

50500,A,*1,1000,-6,33

-1 CURVATURE ADDED: Left medium curvature

51850,SIGN,4,1000,0,0
52000,C,1000,100,750,100,-.00160

-1*****

-1 EVENT Q: single meeting on left medium curvature

53000,A,*1,1000,-6,7

-1 CURVATURE ADDED: Right medium curvature
55500,SIGN,5,1000,0,0
55650,C,1000,100,750,100, .00160

-1*****

-1 EVENT R: single meeting on right medium curvature

56650,A,*1,1000,-6,40

-1*****

-1 EVENT R2: single meeting

57500,A,*1,1000,-6,31

-1 CURVATURE ADDED: Left high curvature
58850,SIGN,4,1000,0,0
59000,C,1000,100,750,100,-.00240

-1*****

-1 EVENT S: single meeting on left high curvature

60000,A,*1,1000,-6,40

-1*****

-1 EVENT T: overtaking on left low curvature

62500,C,1000,100,750,100,-.00080
63200,V, /30, -250, *0, 1, 11, 3, /-12, *30, 2, -3, *0, /30, 2

-1 CURVATURE ADDED
64350,SIGN,4,1000,0,0
64500,C,1000,100,750,100,-.00240

-1*****

-1 EVENT U: single meeting on right low curvature

66000,C,1000,100,750,100, .00080
67000,A,*1,1000,-6,10

0,RMSB,0,Total mean score
68500,RMSE
68500, ES

APPENDIX I: Practice Scenario Event Durations and Navigation Task Placement

Curvature	Event	Event Type	Navigation Number	Navigation Type	RMS Windows	Starting Distance	Duration (in feet)
0						0	1600
Low-L						1600	150
Low-L		Single Meeting			(1750-2000)	1750	250
Low-L						2000	400
0						2400	1000
Med-R						3400	50
Med-R		Single Meeting	1	Low	(3450-3950)	3450	300
Med-R						3750	650
0						4400	1000
Low-R					(5600-6100)	5400	800
0						6200	800
High-L						7000	100
High-L		Overtaking	2	Med	(7100-7600)	7100	700
0						7800	1000
Med-L					(9100-9600)	8800	900
0						9700	1200
High-R						10900	300
High-R		Single Meeting	3	High	(11200-11700)	11200	300
High-R						11500	300
0						11800	1700
Low-L		Overtaking			(13600-14100)	13500	600
Low-L						14100	100
0						14200	800
Low-R						15000	250
Low-R		Single Meeting				15250	50
Low-R		Single Meeting	4	Low	(15300-15800)	15300	250
Low-R						15550	250
0						15800	2100
High-L						17900	300
High-L		Single Meeting			(18200-18450)	18200	250
High-L						18450	350
0						18800	400
0		Single Meeting			(19200-19450)	19200	250
0					(20000-20500)	19450	2750
High-R		Overtaking			(22300-22800)	22200	700
High-R						22900	100
0						23000	500
0			5	High	(23500-24000)	23500	1500
Low-R		Overtaking	6	Med	(25000-25500)	25000	800
0						25800	1300
Med-L						27100	300
Med-L		Single Meeting			(27400-27650)	27400	250
Med-L						27650	350
0						28000	1100
Med-R		Overtaking			(29200-29700)	29100	700
Med-R						29800	100
0						29900	900
0		Overtaking	7	High	(30800-31300)	30800	800
0						31600	1500
High-L						33100	100
High-L			8	Low	(33200-33700)	33200	700
0						33900	1600
End						35500	

APPENDIX J: Real Scenario Event Durations and Navigation Task Placement

Curvature	Event	Event Type	Navigation Number	Navigation Type	RMS Windows	Starting Distance	Duration (in feet)
0						0	1000
0			1	Low	(1000-1500)	1000	1400
0	A	Single Meeting				2400	300
0						2700	1600
Med-R						4300	900
0	B	Overtaking				5200	400
0	B	Overtaking	2	High	(5700-6100)	5600	1500
Low-R						7100	800
0						7900	600
Low-L						8500	300
Low-L	C	Single Meeting			(8800-9050)	8800	250
Low-L						9050	350
0						9400	200
0			3	Med	(9600-10100)	9600	900
Low-L						10500	900
0	C2	Overtaking			(11800-12300)	11400	1000
Low-R						12400	600
Low-R	D	Overtaking	4	High	(13000-13500)	13000	800
0						13800	1100
Med-L					(15200-15700)	14900	1000
0						15900	500
Med-L						16400	400
Med-L	E	Single Meeting			(16800-17050)	16800	300
Med-L						17100	100
0						17200	1500
Med-R			5	Low	(18700-19200)	18700	600
0						19300	300
High-R						19600	200
High-R	F	Single Meeting			(19800-20050)	19800	250
High-R						20050	450
0						20500	1000
High-L			6	Med	(21500-22000)	21500	800
0						22300	2200
Med-R						24500	300
Med-R	H	Single Meeting				24800	250
Med-R						25050	350
0						25400	200
0	H2	Overtaking	7	Med	(25600-26100)	25600	900
High-R						26500	900
0						27400	400
0	I	Single Meeting			(27800-28050)	27800	200
0						28000	600
Med-R	J	Single Meeting				28600	100
Med-R	J	Single Meeting	8	High	(28700-29200)	28700	700
Med-R						29400	100
0						29500	800
High-L					(30600-31100)	30300	900
0						31200	400
Low-L						31600	100
Low-L	K	Single Meeting	9	Low	(31700-32200)	31700	250
Low-L						31950	350
0						32300	1100
Med-L						33400	900
0						34300	300

Curvature	Event	Event Type	Navigation Number	Navigation Type	RMS Windows	Starting Distance	Duration (in feet)
Low-R						34600	100
Low-R	L	Overtaking			(34700-35100)	34700	400
0						35100	400
High - L			10	Low	(35500-36000)	35500	800
0						36300	300
High-R						36600	900
0						37500	400
High-L						37900	100
High-L	M	Overtaking			(38200-38600)	38000	1000
0						39000	1100
Low-R						40100	100
Low-R			11	High	(40200-40700)	40200	700
0						40900	600
Low-L					(41800-42300)	41500	900
0						42400	1100
High-R	N	Overtaking				43500	200
High-R	N	Overtaking	12	Med	(43700-44200)	43700	800
High-R						44500	100
0						44600	1100
Med-R						45700	700
0						46400	100
Med-L	O	Overtaking			(46800-47200)	46500	900
0					(48000-48500)	47400	2100
High-R						49500	100
High-R			13	High	(49600-50100)	49600	400
High-R						50000	400
0						50400	400
0	P2	Single Meeting				50800	200
0						51000	2100
Med-L						53100	200
Med-L	Q	Overtaking				53300	100
Med-L	Q	Overtaking	14	Low	(53400-53900)	53400	100
Med-L						53500	500
0						54000	2700
Med-R						56700	300
Med-R	R	Single Meeting				57000	200
Med-R						57200	300
0						57500	300
0	R2	Single Meeting	15	Med	(57800-58300)	57800	200
0						58000	2000
High-L						60000	400
High-L	S	Single Meeting			(60350-60600)	60400	100
High-L						60500	400
0	S2	Single Meeting	16	Low	(60900-61400)	60900	2700
Low-L	T	Overtaking				63600	700
Low-L						64300	300
0						64600	900
High-L						65500	100
High-L		Single Meeting	17	Med	(65600-66100)	65600	800
0						66400	700
Low-R						67100	300
Low-R	U	Single Meeting				67400	200
Low-R						67600	300
0						67900	600
END						68500	

APPENDIX K: Practice Run Distraction Tasks

Task 1

What is the next right turn?

1. Shamrock 2. N Park Dr.
3. Poolside Dr. 4. Highway 12

The map shows a road network. Highway 12 is a vertical road on the right. Shamrock is a horizontal road at the bottom with a red arrow pointing north. N Park Dr. is a horizontal road above Shamrock. Poolside Dr. is a horizontal road above N Park Dr. A blue line representing a creek is on the right side of the map.

Task 2

Spear St. is ___ of Alora Dr.

1. North 2. South
3. East 4. West

The map shows a street grid. Alora Dr. is a horizontal road in the center. Spear St. is a horizontal road above Alora Dr. Other streets include Higgins St., Anthony St., Wing St., Cross St., Pike St., and Huston St. A red compass rose indicates North.

Task 3

Russell St. is ___ of Shady Ln.

West: East:
14-3=? 18-5=?

The map shows a street grid. Shady Ln. is a vertical road on the right. Russell St. is a vertical road to the left of Shady Ln. Other streets include Chapparel Ln., Putnam Dr., Northern Ave., Adams St., and Sheldon St. A red compass rose indicates North.

Task 4

What is the next left turn?

1. Depot Street Ext. 2. Morey Rd.
3. Mill St. 4. Depot St.

The map shows a street grid. Depot St. is a vertical road on the right with a red arrow pointing north. Mill St. is a horizontal road above Depot St. Depot Street Ext. is a horizontal road to the left of Depot St. Morey Rd. is a horizontal road below Depot St. Other streets include Depot Hill Rd. and Centerville Brook.

Task 5

Turn ___ for Alton Rd.

Left: $14+6=?$ Right: $12+5=?$



Task 6

Sawyer St. is ___ of Union St.

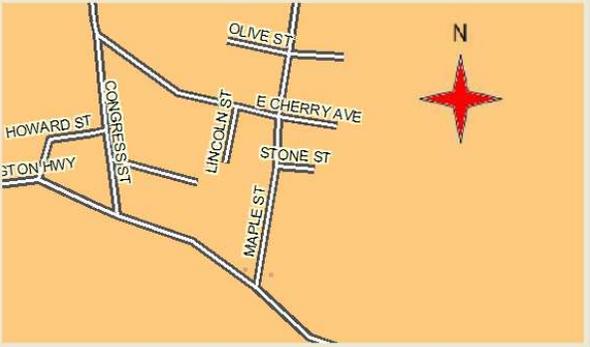
1. North 2. South
3. East 4. West



Task 7

Lincoln St. is ___ of Congress St.

West: $22+6=?$ East: $24+2=?$



Task 8

What is the next right turn?

1. Lord Rd. 2. Weston St.
3. Third Street Ext. 4. Slayton Ave.



APPENDIX L: Real Run Distraction Tasks

Task 1

What is the next right turn?

1. Walker Ln.	2. Bay Rd.
3. Old Coach Rd.	4. Bayberry Dr.

Task 2

Westside Ln. is ___ of Orchard Ln.

North: 7+21=?	South: 3+33=?
------------------	------------------

Task 3

Circle View Dr. is ___ of Alpine Cir.

1. North	2. South
3. East	4. West

Task 4

Turn ___ for Edsands Farm Ln.

Left: 30-5=?	Right: 25-10=?
-----------------	-------------------

Task 5

What is the next left turn?

- | | |
|-----------------|-------------------|
| 1. Westside Rd. | 2. Greenfield Dr. |
| 3. Orchard Ln. | 4. Westside Ln. |



Task 6

Helen St. is ___ of La Cross St.

- | | |
|----------|----------|
| 1. North | 2. South |
| 3. East | 4. West |



Task 7

Belle Ave. is ___ of Park Ave.

- | | |
|----------|----------|
| 1. North | 2. South |
| 3. East | 4. West |



Task 8

Turn ___ for Birchwood Ave.

- | | |
|-----------------|------------------|
| Left:
28-6=? | Right:
34-2=? |
|-----------------|------------------|



Task 9

What is the next right turn?

1. Veterans Rd.	2. Washburn Rd.
3. Sunset Ave.	4. Harris St.

Task 10

What is the next left turn?

1. High Trail.	2. Edsands Farm Ln.
3. Little Bear Hill Rd.	4. Hickory Haven.

Task 11

Turn ___ for Applehouse Ln.

Left:	Right:
27-9=?	32-9=?

Task 12

Wellsville Ave is ___ of Canterbury Arms.

1. North	2. South
3. East	4. West

Task 13

Harold St. is ___ of Little St.

West: $17+8=?$ East: $13+9=?$



A map showing a street grid. Harold St is a vertical street to the west of Little St. A red arrow points north from Little St. Other streets include West St, Brenda Dr, La Cross St, and Chelsea Sq. A red line representing a highway runs diagonally from the bottom right towards the top right.

Task 14

What is the next right turn?

1. Rainbow Ln. 2. Estenes Dr.
3. Sunset Dr. 4. Highway 30



A map showing a road with a red arrow pointing north. The road is labeled with a '30' in a circle. To the right of the road, there are three streets: Sunset Dr, Rainbow Ln, and Estenes Dr. A dashed line is also visible on the right side of the road.

Task 15

Peggy Ann Rd. is ___ of Iroquois Dr.

1. North 2. South
3. East 4. West

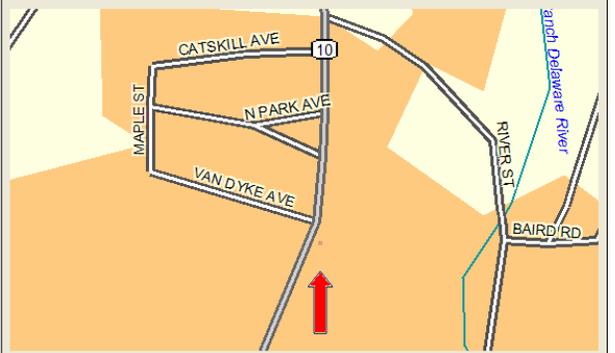


A map showing a street grid. Peggy Ann Rd is a horizontal street to the north of Iroquois Dr. A red arrow points north from Iroquois Dr. Other streets include Lester Dr, Bronk Dr, Foxhurst Dr, Mohawk Trl, and Chippewa Cir.

Task 16

What is the next left turn?

1. N Park Ave 2. Van Dyke Ave.
3. Maple St. 4. Catskill Ave.

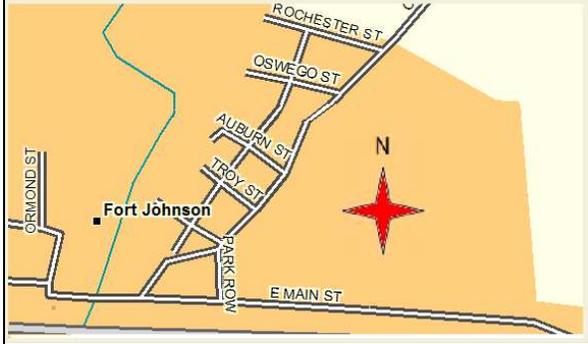


A map showing a road with a red arrow pointing north. The road is labeled with a '10' in a circle. To the left of the road, there are three streets: Catskill Ave, N Park Ave, and Van Dyke Ave. To the right of the road, there are River St and Baird Rd. A blue line representing a river is visible on the right side of the map.

Task 17

Rochester St. is ___ of E Main St.

- | | |
|----------|----------|
| 1. North | 2. South |
| 3. East | 4. West |



APPENDIX M: Table of Descriptive Statistics

Answer Time Data				Lane RMS Error Data			
Curve	Traffic	Average	Std. Dev.	Curve	Traffic	Average	Std. Dev.
0	0	7.1585	3.1224	0	0	4.6686	3.0163
0	Over	10.5177	5.0417	0	Over	4.2474	2.6876
0	Meet	7.0358	2.5753	0	Meet	6.6711	5.2114
L	0	9.9327	3.4598	L	0	6.2297	3.2918
L	Over	10.4986	2.5028	L	Over	5.6576	3.3590
L	Meet	7.1832	1.9480	L	Meet	4.9897	3.6670
M	0	6.8467	2.0497	M	0	6.8940	2.8787
M	Over	7.4616	2.2756	M	Over	6.6990	3.3632
M	Meet	9.2358	2.5573	M	Meet	6.3091	3.7487
H	0	15.0933	5.4557	H	0	9.1928	4.7371
H	Over	12.0132	2.8564	H	Over	7.9972	3.6861
H	Meet	13.0102	4.7863	H	Meet	7.2920	4.3307
Curve	Task	Average	Std. Dev.	Curve	Task	Average	Std. Dev.
0	L	5.2253	1.2362	0	0	3.6764	2.2886
0	M	10.2435	4.5361	0	L	7.3648	5.7748
0	H	8.2188	1.7875	0	M	5.8673	3.2647
L	L	7.1832	1.9480	0	H	3.2738	2.0234
L	H	10.2240	3.0038	L	0	3.8503	2.4276
M	L	7.1587	2.1730	L	L	7.6629	3.2101
M	H	9.2358	2.5573	L	H	7.1918	3.5857
H	L	11.1332	4.0648	M	0	5.2925	2.7186
H	M	13.9759	4.6975	M	L	7.7576	3.0957
H	H	16.9547	5.3700	M	H	8.4056	3.9118
				H	0	6.4720	3.8332
				H	L	11.8961	5.3424
				H	M	9.5571	4.0074
				H	H	8.1803	3.6490
Traffic	Task	Average	Std. Dev.	Traffic	Task	Average	Std. Dev.
0	L	7.7395	3.6166	0	0	5.5743	3.0919
0	M	12.9046	5.7648	0	L	7.6802	4.9068
0	H	13.5470	5.7316	0	M	8.1450	4.6029
Over	L	7.4616	2.2756	0	H	7.5878	3.6337
Over	M	12.5025	4.7284	Over	0	4.9414	2.9677
Over	H	9.3752	2.4589	Over	L	8.1471	3.3885
Meet	L	6.1109	1.9211	Over	M	7.4063	3.6089
Meet	M	11.0216	4.1505	Over	H	5.3224	3.5769
Meet	H	9.2358	2.5573	Meet	0	4.4687	3.3553
				Meet	L	9.2188	5.1842
				Meet	M	7.5725	3.9981
				Meet	H	8.4056	3.9118

