Truck Driver Informational Overload

(MVMA Reference #2163)

Fiscal Year 1992

Final Project Report  UMTRI-92-36

C. C. MacAdam

September 1992

Project Statement:

"This project addresses research directed at assessing the influences of the information systems currently being employed in truck cabs on truck driver attention and driving performance. The project emphasizes defining and developing performance measures and evaluation techniques for investigating driving characteristics during information processing tasks."
The research reported herein was conducted using research funds provided by the Motor Vehicle Manufacturers Association. The opinions, findings, and conclusions expressed are those of the author, not necessarily those of the MVMA.
This document represents the final project report for a study entitled "Truck Driver Informational Overload" sponsored by the Motor Vehicle Manufacturers Association through its Motor Truck Research Committee and associated Operations/Performance Panels. As stated in an initial project statement, the objective of this work was to "provide guidance for developing methods for measuring driving characteristics during information processing tasks." The contents of this report contain results from two basic project activities: 1) a literature review on multiple task performance & driver information overload, and 2) a description of driving simulator side-task experiments and a discussion of findings from tests conducted with eight subjects.

Two of the key findings from a set of disturbance-input tests conducted with the simulator and the eight test subjects were that: 1) standard deviations of vehicle lateral position and heading (yaw) angle measurements showed the greatest sensitivity to the presence of side-task activities during basic information processing tasks, and 2) corresponding standard deviations of driver steering activity, vehicle yaw rate, and lateral acceleration measurements were seen to be largely insensitive indicators of side-task activity.

**Key Words**
- Information processing, overload, driving, vehicle, side-task, driver, performance, task, driver-vehicle, simulator, control, steering, measurement, dynamics, workload

**Distribution Statement**
- No restrictions.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Literature Review</td>
<td>2</td>
</tr>
<tr>
<td>Desktop Driving Simulator</td>
<td>2</td>
</tr>
<tr>
<td>Primary Driving Task</td>
<td>11</td>
</tr>
<tr>
<td>Side-Task Experiments</td>
<td>11</td>
</tr>
<tr>
<td>Experimental Procedure</td>
<td>13</td>
</tr>
<tr>
<td>Data Collection</td>
<td>13</td>
</tr>
<tr>
<td>Data Processing</td>
<td>14</td>
</tr>
<tr>
<td>Results from the Side-Task Experiments</td>
<td>14</td>
</tr>
<tr>
<td>Standard Deviations of Five Driver-Vehicle Responses</td>
<td>14</td>
</tr>
<tr>
<td>Time-on-Task by Subjects</td>
<td>21</td>
</tr>
<tr>
<td>Influence of Vehicle Dynamics</td>
<td>21</td>
</tr>
<tr>
<td>Conclusions</td>
<td>27</td>
</tr>
</tbody>
</table>

Appendix A — Literature Review Bibliographies                           A-1
Appendix B — Example PSDs for Five Driver-Vehicle Responses            B-1
Introduction

This document represents the final project report for a study entitled "Truck Driver Informational Overload" sponsored by the Motor Vehicle Manufacturers Association through its Motor Truck Research Committee and associated Operations/Performance Panels.

As stated in an initial project statement, the objective of this work was to "provide guidance for developing methods for measuring driving characteristics during information processing tasks." At the start of the project, several different approaches appeared possible given the available time and funding constraints. These options included: (A) conducting a limited number of laboratory/simulator experiments to collect a variety of different driver-vehicle response data — but, in a simple driving simulator or workstation environment; or, (B) instrumenting a test vehicle and collecting a restricted and somewhat more noisy set of data — but, for a more realistic on-road environment; and lastly, (C) concentrating efforts instead on a comprehensive review of the literature and limiting project activities to planning and making recommendations for a larger-scale future project. Each of these ideas was offered by various interested parties and each had its own merits. Some combination of these three approaches was also possible. Ultimately, the question of emphasis and where limited resources should be applied was asked of the MVMA panel members. The consensus was that a modest literature review should be undertaken in addition to a limited set of simulator-based laboratory experiments using a desktop driving simulator and side-task arrangement.

Consequently the contents of this report contain results from two basic project activities: 1) a literature review on multiple task performance and driver information overload, and 2) a description of the driving simulator side-task experiments and a discussion of findings from tests conducted with eight subjects.

Lastly, although the term "truck" appears in the project title, the primary focus here was on the driving process and its potential interruption due to side-tasks regardless of the vehicle. However, truck-related applications do appear in some of the references contained in the literature review. Furthermore, a subset of tests conducted in this simulator study (which used a nominal passenger car set of vehicle dynamics in the simulator equations for the baseline vehicle) were repeated with the simulator equations programmed to represent the directional dynamics of a heavy truck in order to check for any sensitivity to vehicle type.
Literature Review

Two bibliographies appear in Appendix A and contain pertinent articles and publications related to the research concerns of this project. The first bibliography of publications, entitled "UMTRI Bibliography on Multiple Task Performance & Driver Information Overload," was obtained from the UMTRI library and is organized in reverse chronological order. The "UMTRI Acquisition Number" appears in the left-hand column as a reference.

The second bibliography appearing in Appendix A is entitled "TRIS/DIALOG Bibliography" and is likewise arranged in reverse chronological order. This bibliography contains a down-load of pertinent references from the national Dialog TRIS (Transportation Research Information Service) database. Abstracts describing the research and findings of the particular works listed in the TRIS database are also included in this bibliography.

While most of these cited works utilize passenger cars as their nominal vehicle, it is evident that most of these studies have direct applicability to other vehicles as well, including heavy trucks. The question of whether or not heavy trucks may somehow be unique, insofar as inducing special qualities that further exaggerate or lessen the findings for passenger car-based studies, is not clear. Driving a truck is not the same as driving a passenger car in many respects. However, the issue of lane regulation and interruption of that basic driving task — upon which this limited study and many in the literature focus — is an area where much overlap between truck driving and passenger car driving probably does exist.

In general, it is noted that many of the cited works are somewhat speculative in nature insofar as raising questions about the potential impact of in-vehicle equipment and side-task activities upon driving performance. Those few studies that have collected actual subject data with side-tasking activities present (e.g., Noy, Nilsson and Alm, Harms) relied primarily upon driver-vehicle responses such as lateral vehicle position, speed regulation, time-to-line crossing (TLC), headway regulation, and driver reaction times as the principal measures of driving performance. Lateral vehicle position is by far the most frequent measure used in these simulator studies, primarily because of its observed sensitivity to side-task activities and the simplicity of measuring it in a simulator.

Desktop Driving Simulator

The primary project activities in this study initially focused on developing and assembling a desktop driving simulator and associated side-task simulator. The plan was to assemble a convenient low-cost system with which to conduct a limited set of
experiments using several different subjects. The basic intent was to provide a straight-line driving scenario with a random-like lateral disturbance such that subjects would have to provide corrective steering inputs to maintain and control the vehicle within its lane. Various types of side-tasks would then be programmed to appear periodically on an adjoining computer screen, thereby requiring some momentary distraction and competition for the driver's attention away from the primary steering task. Data collected with and without side-task interruptions would then be examined to help evaluate the effects of different side-task requirements. The basic test arrangement ultimately assembled for these tests is seen in Figure 1.

The primary driving simulator and screen display were programmed and generated on a Macintosh Quadra 700 (seen on the left of Figure 1). The side-task simulator and its display were programmed to run on any Macintosh model (a Mac II is seen on the right side of Figure 1 and was used for these experiments). The Mac Quadra was selected for use as the primary driving simulator machine because of its speed and ability to generate scenes at a sufficient frame rate of 25 Hz. In addition, the Quadra collected eight channels of driver-vehicle data at 25 Hz, acted as the primary task scheduler for the side-task computer, and was used in most of the post-processing data analyses. Both computers were linked together and communicated activities to one another through their communication serial ports during the subject tests. All of the software was written in C and made extensive use of the Macintosh ROM toolbox routines.

The automobile steering wheel seen in Figure 1 was mounted on a portable board-like assembly. An elastic cord was wound around a hub on the steering wheel rotational axis to provide a modest centering torque for the driver. This was thought to be helpful as a zero-reference cue by some subjects when steering the simulator. A rotary potentiometer attached to the end of the steering shaft provided an electrical measurement of the driver steering angle. The steering wheel signal was digitized during each calculation frame by an analog-to-digital interface card in the Quadra, and that signal was then used in the simulation equations to steer the vehicle.

Figures 2 and 3 illustrate how a typical subject interacts with the simulator. Three side-task activities were programmed to appear periodically and required the subject to read a brief message on the side-task screen and then respond by using either the keyboard or mouse in a relatively simple manner. The look-away behavior exhibited by the subject in Figure 3 during a side-task interaction was fairly typical.
Figure 1. Basic Desktop Simulator Arrangement for Side-Task Experiments.
Figure 2. Subject Interacting with Side-Task Display While Driving the Simulator.
Figure 3. Subject Looking Away From Driving Scene to Respond to Side-Task.
The basic straight-road driving simulator scene is shown in Figure 4. A "vehicle hood" appears at the bottom of the screen and represents the front portion of the vehicle being controlled laterally by the driver. Turning the steering wheel to the right causes the road scene to translate and rotate to the left thereby providing the primary motion cues to the driver. The vehicle dynamics and scene generation (or frame rate) calculations are performed at an update rate of 25 Hz.

Figures 5 and 6 show the basic driving scene and the options available on the "Control Menu" for controlling the simulator operation. Pull-down menus at the top of the screen provide a convenient operating interface for controlling the simulator. The top three items under the control menu seen in Figure 6 provide access to dialog boxes for modifying various low-level parameters such as the integration time step, driver eye height above ground, scaling of window dimensions, etc. The remaining items under the control menu can be used to activate such features as: turning on the random-like disturbance input, triggering the presence of side tasks on the adjoining computer, or recording driver and vehicle response data during simulator tests.

Figure 7 shows how basic vehicle types such as cars or trucks are selected under the "Vehicle Menu." To modify specific parameters of a vehicle at a more detailed level or to alter operating speed, the first menu item ("Modify Vehicle Parameters") can be selected to produce the dialog box seen in Figure 8. In this dialog box, tire properties, fore/aft weight distributions, wheelbase, rotational yaw inertia, and vehicle speed can be further modified to study the effects of changing different vehicle parameters. Most of the experiments conducted under this study used a mid-size passenger car as the baseline vehicle in the simulator dynamics. An additional group of data were also collected for a subset of subjects using a heavy truck as the vehicle programmed in the simulator.
Figure 4. Basic Driving Simulator Scene. (25 Hz Frame Rate)
Figure 5. Driver Steers to Regulate Lateral Vehicle Position.

Figure 6. Menu to Select Various Driving Simulator Options.
Figure 7. Menu to Select Basic Vehicle Type.

![Menu to Select Basic Vehicle Type]

---

Figure 8. Dialog for Modifying a Specific Vehicle Parameter.

![Dialog for Modifying a Specific Vehicle Parameter]
Primary Driving Task

The basic driving task required the driver to maintain the vehicle at some position in the road (the lane center, for example) while being subjected to a random-like steering disturbance (at the front wheels) that causes the vehicle to wander laterally if uncorrected by driver steering. The basic task is similar to driving in an artificial crosswind that gusts randomly from the left or right directions. The magnitude of disturbance was scaled to require a moderate degree of attention by most subjects in order to maintain good control over the lateral position of the vehicle. The disturbance input used in the tests was a sum of 10 sinusoids ranging uniformly in frequency content from 0.1 Hz to 2.0 Hz. The lower frequency components were weighted more heavily than the higher frequency components, thereby providing a more natural crosswind-like characteristic. The vehicle speed was held constant at 55 mph for all the driving task tests.

Side-Task Experiments

During the side-task tests, one of three different dialog boxes was randomly presented to the driver on the adjoining computer screen while the driver simultaneously regulated the vehicle lateral position in the primary driving task. As each side-task was activated and appeared on the adjoining screen, two "beeps" were sounded by the computer to inform the driver of its presence. Figure 9 shows the format of each of the three side-task dialogs. (During testing, only one dialog at a time, of course, appeared on the adjoining screen.) As seen, side-task #1 simply requested that the driver strike the letter "S" on the keyboard. When the letter "S" was correctly selected the dialog box was dismissed.

Side-task #2 requested the driver to move and click the mouse on either "button X" or "button T" ("X" and "T" were randomly selected by the program). The dialog remained on the screen until the correct button was selected.

The dialog for side-task #3 requested the driver to add two single digit integers, type their sum into the answer box, and hit the "carriage return" or "enter" key. Incorrect answers were identified by a "Beep" sound and the driver was requested to reenter the correct sum. Each of the simulated side-tasks was relatively simple to accomplish, though the relative degree of complexity does increase when going from side-task #1 to #2 to #3.

As each side task was triggered by the main simulation computer, a signal level was raised on the side-task computer that denoted the type of side-task being executed and its duration. As each side-task dialog was dismissed, the indicator signal was reset to zero. This signal was recorded by the main simulator computer as an additional time history.
Figure 9. Side-Task Displays #1, #2, and #3.

**Side Task #1**

Hit Letter 5 on Keyboard

**Side Task #2**

Click Mouse on Button: T

**Side Task #3**

Enter Answer, then Hit Return (or Click OK Button with Mouse)
wave-form to provide a record of what types of side-tasks were requested, when they occurred, and how long such interactions lasted during each simulation test.

Experimental Procedure

Testing for each subject took about an hour of time, with the first 20 minutes or so being used to familiarize the subject with the simulator equipment and various side-tasks. Practice sessions were used to allow the subject to gain familiarity with the primary and secondary task scenarios and to adapt to and become comfortable with the basic "handling qualities" of the vehicle being controlled. A set of initial test runs was conducted with each subject to demonstrate that their performance would vary to some degree and likewise improve with practice. Feedback on each subject's performance (e.g., lateral wandering, steering displacements, etc.) was displayed on-screen after each run as a set of standard deviations corresponding to the different system responses.

Once each subject was comfortable with the basic testing scenario, and had more or less stabilized on some consistent level of performance, the actual testing was begun. Each separate test or simulation run lasted for approximately 80 seconds. Tests were conducted in groups of three repeats. The first three runs were conducted with no side-task activities present. The second three repeats were identical to the first three but included the side-tasks. The next three runs were conducted without side-tasks. This pattern was then repeated three times for most subjects, thereby producing nine test repeats with no side-tasks present and nine test repeats with side-tasks present. A few of the subjects were tested for fewer than nine tests due to time conflicts or for other reasons. The high level of consistency in most of the repeated tests indicated that additional testing was buying very little additional information for the limited purposes of this study. If large deviations were observed in the summary statistics over the course of a set of repeated tests, additional tests would have been performed to help improve the quality of the data.

A total of eight subjects took part in the experiments. Six of the subjects were men ranging in age from about 25 to 60. Two of the subjects were women in their twenties.

Data Collection

During each 80-second test, eight channels of data were sampled and stored in a buffer at a rate of 25 Hz. The data collected included the following variables: time, driver steering wheel angle (via the A/d card and steering wheel potentiometer), lateral vehicle position, vehicle yaw rate, lateral acceleration, vehicle heading angle, vehicle lateral velocity, and the side-task signal (4-level step function) from the adjoining computer indicating which side-task was being executed and its duration. At the end of each test, the
data buffer was written to disk and saved with a unique identifying name for later processing.

Also at the completion of each run, statistics summarizing the standard deviations of each of the above time histories were calculated and displayed on screen and also written to the data file. This information provided a quick feedback on subject performance as well as a basic check that the system was operating normally.

Data Processing

Following the collection of test data for all eight subjects, calculations of driving performance measures were performed on five of the driver-vehicle time history response variables (lateral vehicle position, vehicle yaw angle, driver steering wheel motion, vehicle yaw rate, and vehicle lateral acceleration). Conventional standard deviations were calculated on each 80-second time history data set (about its average value). These were then grouped by test subject, response variable, and whether or not side-tasks were present. The standard deviations were then summed and averaged for each driver in tests performed without side tasks and for tests conducted with side-tasks. An averaged standard deviation was then obtained for each of five different driver-vehicle responses, for each test subject, and for conditions with no side-tasks present and with side-tasks present (5 driver-vehicle responses x 8 subjects x 2 side-task conditions).

Calculations were also performed on the side-task signal that contained information on which side-task was being performed and its duration. Measures of time-on-task were calculated for each of the three side-tasks by subject, and of the average number of tasks conducted by each subject in an 80-second test run.

Results from the Side-Task Experiments

Standard Deviations of Five Driver-Vehicle Responses

Figures 10 - 14 show bar charts of standard deviations obtained by processing the time histories corresponding to the five different driver/vehicle system responses. Each chart shows the average standard deviation achieved by each of the eight subjects in tests conducted with and without side-tasks present. Accordingly, each bar represents the average of all repeat runs conducted for a particular subject with (or without) the side-tasks activated.

In Figure 10, corresponding to vehicle lateral position, the standard deviations vary considerably across the population of subjects but do indicate a consistent sensitivity to the presence of side-task activity. For example, subject 1 shows a standard deviation value of 1.3 feet for the side-task tests, but a 23% lower value of 1.0 feet when no side-tasks are
Figure 10. Standard Deviations for Lateral Vehicle Position.

Standard Deviation of Lateral Vehicle Position (feet)

![Graph showing standard deviations for lateral vehicle position with two conditions: No Side-Task and Side-Task.]

Figure 11. Standard Deviations for Vehicle Heading Angle.

Standard Deviation of Vehicle Yaw Angle (degrees)

![Graph showing standard deviations for vehicle heading angle for different test subjects.]
present. The remaining test subjects show similar results for vehicle lateral position in which the presence of side-tasks always results in larger standard deviations. Aside from one subject (#6), the same trend was also true for standard deviations computed for vehicle heading (or yaw) angle seen in Figure 11. [Paired, two-tailed t-tests were conducted on the "No Side-Task" vs. the "Side-Task" data in Figures 10 and 11 for each subject. Lateral vehicle position measurements for subjects #1, #3, #4, #5, #7, and #8 showed significance levels of 0.0001, 0.0064, 0.0039, 0.0200, 0.0400 and 0.0003 respectively. Heading angle measurements for the same subjects displayed significance levels of 0.0006, 0.00591, 0.0004, 0.0013, 0.0049, and 0.0054 respectively. Corresponding data on subjects #2 and #6, which displayed less sensitivity to side-task activity, indicated significance levels of 0.234, 0.497 for lateral displacement, and 0.0886, 0.815 for heading angle.]

In Figures 12 and 13, standard deviations are shown for driver steering angle response (at the road wheel) and vehicle yaw rate. Interestingly, these response variables indicate virtually no sensitivity to the presence of side-task activity across all subjects. This is somewhat surprising since vehicle heading angle (Figure 11) is the integral of yaw rate seen in Figure 13, yet only the heading angle response indicates a consistent sensitivity. One explanation for this could be that the yaw rate signals generated by the driver-vehicle systems with and without side-tasks have the same amplitudes but different dominant frequencies. If the side-task yaw rate responses have somewhat more power concentrated at lower frequencies than the non-side-task responses, the integral signal (heading angle) for the side-task responses could have larger root mean square (RMS) or standard deviations.

Another way of seeing this is to consider the power spectral density (PSD) plots of the yaw rate signals with and without side-tasks. An example set of such plots is contained in Appendix B corresponding to Subject #1, not only for yaw rate but for each of the other five responses as well. The PSDs of yaw rate seen in Figure B.2 of Appendix B show two plots entitled "No Side-Task Activity" and "With Side-Task Activity." The square root of the area under each set of curves is equal to the standard deviation. These areas are approximately equal as Figure 13 (obtained by time-domain processing) already suggests. However, the bottom chart corresponding to side-task experiments shows a larger level of power in the 0.2 to 0.5 frequency range. Since the PSD of yaw angle (the integral of yaw rate) is obtained by multiplying the yaw rate PSD by \((1/\text{frequency})^2\), the resulting yaw angle PSD for side-tasks will have a larger set of magnitudes at low frequencies (as confirmed by Figure B.5). If the square root of the areas under the heading angle PSDs of Figure B.5 are then calculated, distinctly larger standard deviations should be observed for
Figure 12. Standard Deviations for Driver Steering Input.

Standard Deviation of Vehicle Front Wheel Steer Angle (degrees)

- No Side-Task
- Side-Task

Figure 13. Standard Deviations for Vehicle Yaw Rate.

Standard Deviation of Vehicle Yaw Rate (deg/sec)
the side-task activity tests. This does indeed occur as the standard deviation results obtained alternately from time history calculations of Figure 11 clearly demonstrate.

One physical explanation for a "low-frequency shift" in yaw rate and steering angle responses during side-task experiments could be that during side-tasks periods, the steering activity is largely non-varying and near zero as the driver attends to the side-task activity. This would also produce a non-varying and near zero yaw rate signal. Consequently, imposing an intermittent zero-like signal on both the yaw rate and steering signals would have the effect of lowering the overall frequency content of these signals. Since vehicle heading angle and lateral position responses involve integrations of these signals, both of these responses are free to increase or to continue varying during side-task periods when the steering angle is near zero and unchanging.

Lastly, in Figure 14, results of the standard deviation calculations on vehicle lateral acceleration are shown. Here, some modest sensitivity to side-task activity is apparently present but is quite small. (The vehicle lateral displacement is effectively a double integration of this signal and the same line of reasoning discussed above with regard to PSDs and power shifts in the frequency domain applies here, as well.)

Figure 14. Standard Deviations for Vehicle Lateral Acceleration.

![Figure 14](image)
If the information contained in Figures 10-14 is combined and averaged across all drivers, and the ratio of side-task results to non-side-task results is plotted for each of the five response variables, Figure 15 is the result. The non-side-task results are, of course, indicated by the unity value on this graph. Values above unity indicate the increase in standard deviations that occur for each of the five system response variables. This plot combines all of the subject measurements to identify those driver-vehicle responses that are

**Figure 15. Normalized Performance Ratios for the Five Driver-Vehicle Response Variables.**

Ratio of: \[ \frac{\text{Side-Task Performance}}{\text{No Side-Task Performance}} \]

Averages Across All 8 Subjects

<table>
<thead>
<tr>
<th>Driver-Vehicle Response Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Lateral Vehicle Position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Vehicle Yaw Rate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Driver Steering Wheel Angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Vehicle Lateral Acceleration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Vehicle Heading (Yaw) Angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* (As defined by the standard deviation of each time history response)
the best candidates for predicting sensitivity to side-task activities. As noted above, vehicle lateral position and heading (yaw) angle stand out as the two most sensitive indicators. If a paired, two-tailed, t-test of these combined data are performed for the lateral position and heading angle measurements ("side-task" vs. "no side task"), a significance level of 0.028 is obtained for lateral position and a level of 0.0073 for heading angle.

The same data can also be plotted on a graph, as shown in Figure 16, that starts at unity instead of zero to better visualize the differences in standard deviations. Again, unity represents the non-side-task results on this graph. On average, the standard deviation

Figure 16. Variations in Driving Performance Due to Side-Tasks for Each of the Driver-Vehicle Response Variables.
calculations across all subjects tested indicate that vehicle lateral position has the highest sensitivity to the presence of side-tasks with an amplified value of about 22%. Yaw angle, next in sensitivity, has an amplified value of about 15%.

**Time-on-Task by Subjects**

Figure 17 shows the average amount of time spent by each subject on each of the three side-tasks. The horizontal dashed line across each graph represents the average of all subjects for that particular task. Task difficulty did increase when going from task #1 to #2 to #3. This increased difficulty is also likely reflected in the increased time-on-task values associated with tasks #2 and #3. On average, approximately 33% of each 80-second test run was spent on side-task activities by each subject.

The number of tasks, on average, requested and performed by a subject during one 80-second driving test is seen plotted in Figure 18. The total number of tasks per driving test was approximately five, with over twice as many #1-type tasks being completed than #3-type tasks. The reasons for the greater number of #1-type and #2-type tasks being completed relate, in part, to the shorter completion times for the #1-type and #2-type tasks (and hence the greater opportunity for one to be requested and completed again in a finite testing period). Some unintended bias in randomness may have also been present in the selection scheme used for triggering the side-task events.

**Influence of Vehicle Dynamics**

To obtain an estimate of how these results may be influenced by the type of vehicle being controlled by the subject in the primary steering task, three of the eight subjects were also tested using a heavy truck set of vehicle dynamics in the simulator in place of the baseline passenger car dynamics. The results of these "heavy truck" tests are seen in Figures 19-21.

Figure 19 is analogous to Figure 16 seen previously for the passenger car dynamics and all eight subjects. In Figure 19, the normalized results of the subset of three subjects indicates a strong similarity to the results seen in Figure 16 with vehicle lateral position and heading angle standing out as the two key responses variables.

In Figure 20, the time-on-task for the same three subjects is seen for the truck tests. Again, the results are in basic agreement with those of Figure 17 for the passenger car tests.

Lastly, in Figure 21, the average number of tasks performed by the same three subjects are graphed similarly to those seen in Figure 18. The number and distribution profile is nearly the same as that seen in Figure 18 for the passenger car results.
Figure 17. Average Time on Side-Task by Subjects.

Average Time on Task #1 (seconds)

Average Time on Task #2 (seconds)

Average Time on Task #3 (seconds)
Figure 18. Profile of Side-Task Activity Per 80-Second Test Period. Averaged Over All Subjects.

Average Number of Side-Tasks Conducted Per 80-second Test Run.
Figure 19. Variations in Driving Performance Due to Side-Tasks for Each of the Driver-Vehicle Response Variables. Truck Dynamics Used in Place of Passenger Car Dynamics.

Variation in Driving Performance Due to the Presence of Side-Tasks. Unity Value Represents the No-Side-Task Condition.

(Performance defined by the standard deviation of each time history response)

Heavy Truck Directional Dynamics Instead of Passenger Car

3 Subjects instead of 8

Driver-Vehicle Response Variable

Driver-Vehicle Response Variables:
1. Lateral Vehicle Position
2. Vehicle Yaw Rate
3. Driver Steering Wheel Angle
4. Vehicle Lateral Acceleration
5. Vehicle Heading (Yaw) Angle
Figure 20. Average Time on Side-Task for a Subset of 3 Subjects and the Heavy Truck Dynamics.

Average Time on Task #1 (seconds)

Average Time on Task #2 (seconds)

Average Time on Task #3 (seconds)
Figure 21. Profile of Side-Task Activity Per 80-Second Test Period. Averaged Over 3 Subjects. Heavy Truck.

Average Number of Side-Tasks Conducted Per 80-second Test Run for Subset of 3 Subjects and the Truck Dynamics.
Conclusions

Based upon the desktop driving simulator tests conducted in this study with eight subjects and the resulting data processing of associated subject-vehicle time history measurements, the following conclusions and observations are offered.

- Standard deviations of vehicle lateral position and heading (yaw) angle measurements show the greatest sensitivity to the presence of side-task activities during basic information processing tasks. Unfortunately, these two signals are also difficult to accurately measure under full-scale test conditions — as might be used to ultimately evaluate actual in-vehicle equipment. Two recent studies cited in the literature review of Appendix A (Noy, 1989; Nilsson and Alm, 1991) that utilized moving-base simulators for studying driving performance with side-task activities report similar findings regarding lateral position sensitivity. Interestingly, the standard deviation amplification for lateral position reported by Noy using a full-motion simulator was similar to the value reported in this study (26% versus 22% seen in Figure 16). As noted in the discussion of results, these observed variations between "no-side-task" and "with-side-task" results were statistically significant for six of the eight subjects when examined on a subject-by-subject basis. Combined subject data indicated significance for lateral position measurements at a level of 0.028 and for heading angle measurements at a level of 0.0073.

- Standard deviations of driver steering activity, vehicle yaw rate, and lateral acceleration measurements were seen to be insensitive indicators of side-task activity. Since these three signals are very commonly measured during full-scale test programs (as might be envisioned for evaluation of actual in-vehicle IVHS equipment), the likelihood of successfully processing such signals (in the conventional time-domain manner) would probably be poor. However, an alternate processing scheme would be to obtain the frequency-domain PSDs of these signals and to utilize the low frequency components as measures of side-task sensitivity. In this same vein, the yaw rate and lateral acceleration PSDs could be processed in the frequency domain to derive heading angle and lateral position PSDs. (This approach was discussed briefly in the report in connection with the standard deviations of yaw rate and the example PSD plots appearing in Appendix B.)

- The basic side-task findings reported above showed no particular sensitivity when the vehicle dynamics of the controlled vehicle were modified from a passenger car to that
of a heavy truck. A subset of three test subjects produced nearly identical normalized results for the heavy truck vehicle as for the passenger car. (The absolute standard deviations of most responses were smaller for the truck than the car using the same disturbance input, but produced the same sensitivities when normalized by their corresponding no side-task measurements. See Figures 16-18 versus Figures 19-21.) This observation might be expected since the steering control requirements that constitute the primary task activity (lane regulation) for the driver in both cases is very similar in nature — assuming reasonable car and truck directional dynamics. It is certainly true that in reality the car and truck driver environments are nothing alike, and that additional realism deriving from vibratory motions, control placements, and ergonomic matters may play a role here. However, absent of those very real additional influences on driving performance, the directional dynamics per se of the vehicle does not appear to have significant influence on altering the sensitivity of driving performance to side-task activity.

- The amount of subject-to-subject variation in performance was greatest for the lateral position and heading angle responses, regardless of whether or not side-tasks were present. While these two system responses varied considerably across the subject pool, they were accompanied by roughly the same amount of steering, yaw rate, and lateral acceleration. This would indicate that although all subjects used approximately the same level of steering effort/activity and were able to control the vehicle yaw rate and lateral acceleration within a similar range, their respective abilities to also control lateral position and heading angle within a similarly restricted range were not as effective.

- If a driver's ability to control vehicle lateral position and orientation (heading angle) is viewed as one reasonable indicator of driving performance, then the results of these laboratory simulator experiments would suggest a degradation in driving performance when side-task activities (of the type used here) are present. However, it should likewise be noted that the levels of degradation observed for the side-task experiments were less than the amount of subject-to-subject variations in those same vehicle responses (with or without side-tasks present). Such person-to-person variability typically exhibited by human subjects should of course be expected. Everyone has their own "style" or preferred behavior of driving. In many ways, this "style" often determines what levels of driving performance are exhibited by individual drivers. Insofar as the data may show that side-tasks produce a consistent one-way change
(i.e., degradation or improvement) in driving performance for each individual driver, regardless of each driver's preferred level of performance without side-tasks present, the focus of attention then shifts to a question of "how much of a change in driving performance is significant with regard to safety?". Needless to say, that very difficult question is well beyond the limited scope of this modest study.

- The desktop driving simulator developed under this work is seen as a useful first-stage evaluation tool for guiding the direction of basic research related to driver-vehicle interactions. The ability to quickly set up and test out a concept with such a device prior to committing to a more extensive full-scale program has proven to have more merit than originally anticipated.

- Full-scale tests with typical in-vehicle equipment could be conducted to further assess and refine the results reported in this study. Questions regarding the effect of simulator realism and the impact of actual driver environments could also be addressed in such tests. One approach would be to conduct controlled driver-vehicle tests at an appropriate proving ground facility with a small group of drivers. Alternatively, a similar study could be undertaken with an appropriate moving-base simulator.
Appendix A

Bibliographies on
Multiple Task Performance & Driver Information
Overload
from
the UMTRI Library
and
the Dialog Transportation Research Information
Service Database
UMTRI Bibliography on Multiple Task Performance & Driver Information Overload

UMTRI Library Acquisition #


79922 A15 USER PERCEPTIONS AND SAFETY IMPLICATIONS OF IN-VEHICLE NAVIGATION SYSTEMS. Jovanis, P. P.; Kitamura, R. California University, Davis. 1989. 4 p.


72763 THE EFFECT OF VISUAL TASKLOAD ON CRITICAL FLICKER FREQUENCY (CTF) CHANGE DURING PERFORMANCE OF A COMPLEX MONITORING TASK. Thackray, R. I.; Touchstone, R. M. Civil Aeromedical Institute, Oklahoma City, Okla. 1985. 18 p.


47267 A08 THE ON-LINE USE OF PERFORMANCE MEASURES TO PREDICT DRIVING FATIGUE. Attwood, D. A.; Scott, P. L. Canada, Transport Canada, Road Safety Unit, Downsvie, Ontario. 1981. 5 p.


54531 See Journal ALCOHOL EFFECTS ON DRIVER PERFORMANCE UNDER CONDITIONS OF DIVIDED ATTENTION. Brewer, N.; Sandow, B. Burwood State College, Australia; Adelaide University, Road Accident Research Unit, Australia. Ergonomics, Vol. 23, No. 3, March 1980, pp. 185-190. 1980. 6 p.

43531 A05 PRACTICAL MEASURES OF DRIVER TASK DEMAND. Armour, M. Australian Road Research Board, Vermont South. 1979. 13 p.


DRIVER WORK LOAD FOR VARIOUS TURN RADII AND SPEEDS. McDonald, L. B.; Ellis, N. C. Midwest Research Institute, Kansas City, Mo.; Texas A&M University, College Station, Industrial Engineering Department. Transportation Research Record, No. 530, 1975, pp. 18-30. 1975. 13 p.


THE USE OF BEHAVIOURAL METHODS TO ASSESS TRAFFIC HAZARD. Macdonald, W. A.; Cameron, C. Australian Road Research Board, Victoria. 1974. 27 p.

30534 A07 RELATIONSHIP BETWEEN PREDICTED STRESS AND MEASURED ATTENTIONAL DEMAND IN A SIMULATED DRIVING TASK. McDonald, L. B.; Ellis, N. C. Midwest Research Institute, Kansas City, Mo.; Texas A&M University, College Station. 1974. 6 p.

32775 BEHAVIOURAL PROBLEMS ASSOCIATED WITH A TRANSITION TO POLARIZED VEHICLE LIGHTING. Rumar, K. Uppsala University, Traffic Safety Research Group, Sweden. (1973) 54 p.


08168 EFFECTS OF MUSIC ON WORK PERFORMANCE. Wokoun, W. Human Engineering Laboratories, Army Department, Md. 1968. 36 p.

06474 TASK CAPABILITY WHILE DRIVING. Quenault, S. W. Road Research Laboratory, Crowthorne, England. 1968. 20 p.


The pilot of an aircraft, like the driver of an automobile, must process a wide range of visual material as well as a potential number of auditory signals, often concurrently. This publication provides a detailed look at human factors relating to aerospace and automotive applications. Chapter topics include: selective visual attention; command and status displays; navigational displays; color and pictorial displays; head-up (HUD) displays; automation; and dual task performance and pilot workload.


Automobile navigation systems are undergoing rapid technological evolution following advances in microprocessors and artificial intelligence. The present study was initiated to investigate the human factors of intelligent automobile displays with a view towards determining the need for design guidelines. The experiment was designed to examine the relationship between drivers' visual attention and performance under concurrent multitask conditions. Twenty young male and female students with normal vision and a minimum of 3 years driving experience were randomly assigned to two groups in a mixed, three-factor experiment. Subjects drove in a moving-base simulator and performed cognitive tasks on a CRT display which was located on the instrument panel to the right of the driver. The two display tasks, a spatial perception task and a verbal memory task, were designed to place differential demands on cognitive resources. Subjects were instructed to perform their best on the display and driving tasks, giving priority to the driving. Display task difficulty and driving difficulty were manipulated within subjects. Task Type (memory and perception) was the between-groups factor. Eleven dependent variables provided measures of driving performance, attentional behaviour, display task performance and workload. In addition, on-line eye movement sampling indicated whether the subject looked at the roadway or at the computer display. Results are discussed in relation to the need for ergonomics guidelines for the design of navigation displays.

The Conference was sponsored jointly by IEEE, the Vehicular Technology Society, Toronto Chapter of IEEE, the Ontario Ministry of Transportation, and Transport Canada.

T. Rockwell, SPARE VISUAL CAPACITY IN DRIVING REVISITED. NEW EMPIRICAL RESULTS FOR AN OLD IDEA. VISION IN VEHICLES II - PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE ON VISION IN VEHICLES, NOTTINGHAM, UK, 14-17 SEPTEMBER 1988.

The introduction of electronic technology in the automobile has opened the driver to new features and new information systems, but at the same time has increased his visual workload. Touch crt's, navigation systems, diagnostic systems, sophisticated stereos, trip monitors and dynamic graphics represent some of the added visual demands to a task which is already visually demanding. In fact, arguments have been made to introduce ordinary TV programming into the vehicle. With the ability of the electronic engineer to introduce more exotic displays in the future, it is time to reassess how much visual demand off the road scene the driver can manage, and whether display/control designs can influence this visual workload. Alternatively, can driver "in car" visual sampling behaviour be used to help evaluate the adequacy of display and control design? The increase in visual workload from "in car" information systems depends upon whether use of the control/display is elective or forced by the driving task. For example defroster and windshield wipers require immediate and accurate response while elaborate cassette features can wait until the driver's outside visual workload is reduced to permit inside search. This requires an assumption of rational behavior for the driver's allocation of the visual function. (anyone who has tried to use a stereo in a strange rental car at night would probably confess to misallocation of visual capacity.) Since most electronic displays being introduced in cars today have little positive safety benefits, they could be construed as increasing the accident potential if drivers attend to them to the detriment of roadway visual sampling. The "visual cost" of electronic displays and controls which offer positive safety benefits, however, might be cost effective. Displays which reveal the presence of cars in the driver's "blind spot" or those which could present relative speed and headway in car following could, in effect, reduce the overall visual demands of the driver.
What is needed is data to construct typical sampling patterns to describe normal "in car" vs "outside car" visual sampling. (TRRL)

A review of the demands of the driving task reveals that drivers require a high level of perceptual and information processing skill to operate modern vehicles safely and efficiently. These basic skills, as they relate to driving, are examined and their relevance to vehicle design is discussed. Potential difficulties associated with the presentation of information in vehicles, including 'high technology' displays, are outlined.(a)


(Author/TRRL)

A-8

Drivers approaching intersections have only a short time interval to make multiple decisions such as their intended direction of travel, whether any other vehicle is likely to conflict with them, what signs they have to legally obey. This article elucidates ways in which this decision making is not optimized, concentrating on ways the environment can reduce the drivers' performance. Violation of general expectancy, of specific expectancy, and the consequences of information overload are the three factors considered. Examples in the New Zealand situation are given, including a dangerous intersection located at Tatuanui in the Piako County.


The Destination Guidance and Information System (ALI) provides the individual motorist with the ability (taking the actual traffic situation into consideration) to be guided to his destination by the optimum route and be quickly informed about obstructions caused by traffic and weather. In addition, this system provides the local traffic authorities with the knowledge not only of the flow of traffic on the selected routes, but also the desired destination of the ALI vehicles. With this information better predictions can be made for the regulation of the flow of vehicles and prevention of overload of certain routes. Three types of devices, located on the vehicle (transmitter, receiver and control unit, with display panel and driver input), on the road (induction loops), and in the control centers (computer), are used to exchange information between vehicles and fixed ground sites. The costs are relatively low, especially due to the fact that existing equipment for traffic data collection can be incorporated into this system. It is estimated that in mass production the vehicle unit would cost approximately as much as an automobile radio. At the moment a large-scale test is being prepared in the Ruhr area (Germany), the results of which will be available by the end of 1980. Translated from German (original 5p; translation 14p)


Information reaching the driver from the road via the sense organs lead to measurable changes in responsiveness. For various reasons the result can be an overloading of available capacity. Because of a high technical input the necessity for mastering the mechanics of the vehicle has already been reduced to a minimum. On the other hand, the stream of information about the environment is so comprehensive that it raises the question of a possible reduction in the density of the information received. From the relevant medical viewpoint, the processing of internal information gains particular significance in a traffic context. External information must constantly be compared with internal information to make possible a standard of behaviour in traffic which is equal to the situation. This behaviour cannot be present if, as a result of mental limitations, these regulation processes cease to be effective (e.g. as a result of food consumption and alcohol and certain drugs). To make a further technical improvement in the standards of internal safety in the passenger car does not seem a sensible move, since investigations have shown that this is accompanied by an increased willingness to take risks. A particular problem is the behaviour of older people in traffic. Owing to natural changes, the necessarily continuous procedure of information processing is no longer mastered. This can lead to breakdowns in communication, in traffic as in other situations. On the question of prevention it is argued that along with attempted and actual control, an attitude of partnership should be propagated as a model of social responsibility and competence.


Sensory overload, or information overload, as related to the driver is discussed, with particular reference to the driver education process. Sensory overload occurs when the human mind is fed information too quickly or in too great a quantity for it to react in a normal manner. This can occur at three different levels (the sensory or perceptive level, the cognitive or thought level, and the decisional or judgmental level). A person's threshold for sensory overload can be lowered by such factors as emotional turmoil, fatigue, and drugs. Since it is known that there are over 1700 different parts of the driving task, it becomes easy to show
how sensory overload can occur in the person who drives, especially if that person is inexperienced in a particular situation, such as driving in fog. The driver educator should be aware that the sensory overload phenomenon does exist, and that it can occur during the course of instruction. Through the use of simulators, the instructor can introduce the student to situations requiring split-second responses without the serious consequences of mistakes under actual conditions. These situations can be rerun and action frozen at selected points for emphasis and further discussion. In this manner, the instructor can increase the student's stored knowledge and stimuli-processing abilities to avoid panic and decline in performance during a critical moment. During the in-car phase of instruction, the driver educator should be aware that comments to the student can contribute to possible sensory overload. By giving instructions before the car is in motion and limiting additional comments to directions and necessary verbal cues, the instructor can eliminate himself/herself as a possible overload stimulus. Commentary driving, either by the driving student or the observing students, can also reduce sensory overload.


Papers and abstracts (186) are presented on the application of human factors theory, covering ergonomics in industry, performance evaluation and workload, visual performance in driving, and display codes and dimensions. Other topics include training (systems, media, and methodology), operator performance in driving, safety in high risk environments, training and simulators, communication and computers, visual performance in aviation, and women at work. Current issues in the design of training and evaluation systems are presented, as are driver performance criterion development, visual performance, and human factors in manual materials handling. Other topics include human factors with ubiquitous payoff (training and instructions for new telephone systems), product design and the consumer, cognitive and motor performance, and visual displays and performance. Impact of human factors on developing effective organizations is addressed, as well as human factors standards impact on equipment design, and the human factors approach to energy conservation and technology. Anthropometry and design, system design and methodology, performance and stress, and safety on wheels are also covered. Other topics include human factors applied to meeting the needs of older and/or handicapped persons, impaired driver performance, and safety on foot. Also considered are experimental design (extension of the two level factorial problem), anatomical measurements of civilian populations, transportation and environmental safety, and product liability/product safety. Final sections cover environmental design in the micro-environment, and software considerations in computer systems. Includes HS-025 239--HS-025 263.


Interviews with 105 drivers who had been involved in one or more accidents while under the influence of alcohol, conducted in 1973, indicated that information overload may be a causal factor in accidents where alcohol is involved. A laboratory experiment was conducted using a computerized system in which the subjects were instructed to try to hold a small circle between two continuously moving parallel lines shown on the computer display by adapted steering movements. Three groups of 12 male university students each were used for the study, with the groups being given a placebo drink, a low alcohol dosage drink producing a blood alcohol concentration (BAC) of 24 milligrams of alcohol per 100 milliliters, or a high alcohol dosage producing a BAC of 57 milligrams per 100 milliliters. The computer recorded the number of times the circle touched or transgressed the limits of the road and the time during which the circle was off the road. This study seemed to yield evidence that people under the influence of alcohol doses of 60 milligrams per 100 milliliters, or even less if only the results from the older subjects are considered, become slower in handling situations that require swift changes in their response choices, as often happens in critical traffic situations. Paper from the Proceedings of the International Conference (6th) held in Toronto, 8-13 Sep 1974. Partly supported by the 'Fonds voor Kollektief Fundamenteel Onderzoek' grant 10, 170


Experiments on the rate of human information transmission show that the relationship between performance and demand depends upon time history of demand; beyond overload, performance does not recover at the expected rate as demand is reduced. The resulting 'hysteresis' effect increases after moderate doses of alcohol. Some implications of these results in real-life situations are discussed. (A) /TRRL/
Vision appears as the common denominator in the complex of man, the vehicle, the highway (road complex) and the environment. Modern features of cars (e.g., power steering, power braking, reduction of wind noise, air conditioning allowing driving to be done with windows closed thus eliminating road and traffic noise) have left man dependent upon the visual sense for the major sensory input of information about the speed of his/her vehicle, its position on the highway, and its position in relation to other vehicles on the highway way or fixed objects along the highway. Improved highway design and vehicle suspension have removed the feeling of the centrifugal forces by which the driver formerly estimated the speed and direction of his/her vehicle. Estimates and measurements have shown that man can fixate an event every half-second, which means that for every 88 feet he/she travels at 60 mph, the driver can handle and assimilate two events a second. If there is not enough time to perceive all the events that are operative in a traffic complex, then the driver must slow down to be able to process them each in turn. This really is why speed limits are reduced in congested areas. It is necessary to determine, from the standpoint of vision, the meaningful traffic events that the driver must perceive and then determine how best to make these events visible to the driver through the use of clear visibility of the surrounding highway, proper lighting of the vehicle fore and aft, proper choice of the color of lights, and meaningful intervehicle communication by signalling. The driver must be taught how to perceive these events, synthesize them, catalog them, put them into meaningful groups, and act upon them. The vehicles and highways of the future must provide rapid recognition of visual signals as well as provide a visual environment that will reduce visual fatigue as much as possible from atmospheric and artificial sources. The visual characteristics of the road must provide clear visibility, a minimum of signs, signals, and guidelines, but a maximum of visual guidance from those cues which research will find to be the most meaningful. Above all, the visual environment must be free from irrelevant, distracting material but not sufficiently monotonous to cause lack of attention. The roadway environment must be visually pleasing, must convey a directional characteristic to the highway, and must provide freedom from visual conflict, freedom from unusual changes in illumination, and freedom from perceptual overloading of the visual system. Even if all the above requisites were met, the problem still exists of placing compatibly 95.6 million biologically and psychologically different drivers in their 90 million cars on highways that are even today inadequate. Based on a paper presented at American Assoc. for Automotive Medicine Annual Meeting, Rochester, Minn., 22 Oct 1965.
Appendix B

Example Power Spectral Density Plots
for Five Driver-Vehicle Responses

Subject #1
Figure B.1 PSDs of Front Wheel Steer Angle With and Without Side-Tasks Present. Three Repeat Tests Each. Subject #1.

PSD of front wheel steering angle - deg $^2$/Hz

No Side-Task Activity

With Side-Task Activity

B-2
Figure B.2  PSDs of Yaw Rate With and Without Side-Tasks Present.  
Three Repeat Tests Each.  Subject #1.

PSD of yaw rate - deg/s $^2$/Hz

No Side-Task Activity

With Side-Task Activity
Figure B.3 PSDs of Lateral Acceleration With and Without Side-Tasks Present. Three Repeat Tests Each. Subject #1.

PSD of Lateral Acceleration - $g's^2/Hz$

**No Side-Task Activity**

**With Side-Task Activity**
Figure B.4 PSDs of Lateral Position With and Without Side-Tasks Present. Three Repeat Tests Each. Subject #1.

PSD of lateral position - $\text{ft}^2/\text{Hz}$

No Side-Task Activity

With Side-Task Activity
Figure B.5  PSDs of Heading Angle With and Without Side-Tasks Present. Three Repeat Tests Each. Subject #1.

PSD of heading angle - deg²/Hz

No Side-Task Activity

With Side-Task Activity

B-6