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Driver Workload as a Function of Road Geometry: A Pilot Experiment

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16. Abstract

This experiment examined the relationship between road geometry, workload ratings, and predictions from Wierwille's workload model, and provided representative performance data for driving a simulator. Eight people drove the UMTRI driving simulator for six sets of roads (varying in sight distance from 150 to 1140 feet (46 to 347 m), each having a fixed sequence of five winding road segments of varying width (lanes of 7.5 to 12 feet [2.3 to 3.7 m]). The six sets were presented in a counterbalanced order. Traffic was not shown.

The standard deviation of lateral position was 1.1 feet, with drivers using more of the road as land width increased (0.9 feet [.27 m]) for 7.5 foot lanes to 1.4 feet (.43 m) for distance, except for the 150-foot sight distance.

In terms of predicting performance, the mean and standard deviation of speed were not correlated with workload ratings, Wierwille workload estimates, or other performance measures. The standard deviation of lateral position was correlated with workload ratings. These data suggest that use of the standard deviation of speed and lateral position as measures of driving workload merits reconsideration when workoad is light and traffic is absent.

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INTRODUCTION

Background

Motor vehicle crashes are among the leading causes of death of children and adults, claiming between 40,000 and 50,000 lives each year in the United States (U.S. Department of Transportation, 1989; 1990; Evans, 1991). A significant number of these crashes involve medium and heavy trucks. In 1990, 3 percent of the Nation's motor vehicle fleet was medium and heavy trucks; yet in that year 8 percent of fatal crashes involved trucks (U.S. Department of Transportation, 1993).

Driving a truck can impose a significant workload on the driver, a workload which under the proper conditions can overload the driver and lead to an accident. Sources of workload include traffic, variations in road geometry, in-vehicle controls and displays, and passengers.

This particular report explores workload associated with road geometry. "Tight radius curves, especially in combination with abrupt grade changes, and compound or extended curves were found to threaten the controllability of both trucks and cars, contributing to severe crashes." (Sweatman, Ogden, Haworth, Vulcan, and Pearson, 1990, p. 250). Road alignment (especially horizontal curvature) was considered to be a factor in 48% of the fatal crashes involving heavy vehicles in this Australian study.

Beyond possible loss of control and the consequent accidents, driving on complex roads demands more driver attention (leading to greater driver workload) than does driving on straight roads. People have limited "resources," and increasing the demands on these resources can have a negative impact on performance. Workload-related limitations may be perceptual (many displays competing for visual attention), cognitive (processing limitations), or motor (more manual controls to be operated than there are limbs available).

Historically, there has been considerable effort to study workload (generally mental workload), in military and aerospace contexts. The intent of these studies was to understand how to avoid overloading astronauts and pilots, who are often performing highly critical operations where task timing and accuracy are paramount. There has been little effort to extend those results to driving tasks, however. This experiment examines the effect of road geometry on driver workload.

Workload Measurement Techniques

Direct and indirect measures of performance have been made in various experimental situations with some success to ascertain a level of workload. However, individuals have differing capacities for interpreting and using multiple sources of information and executing physical tasks. Accordingly, using a measurement of workload to determine how easy or difficult tasks are to perform in general will be challenging. Similarly, since individual capabilities vary, determining a person's remaining resources to handle new tasks or information will also prove challenging. There is yet to be established a single metric or measurement that reflects workload per se, but current strategies to document changes in task performance give insight to workload levels.

There are five broad categories of workload measurement techniques: (1) primary task measurement, (2) secondary task measurement, (3) physiological measures, (4) subjective techniques, and (5) input control (Casali and Wierwille, 1983; Christ, Hill, Byers, Iavecchia, Zaklad, and Bittner, 1993; Lysaght, Hill, Dick, Plamondon, Linton, Wierwille, Zaklad, Bittner, and Wherry, 1989; Moray, 1979; Wierwille, 1979; Williges and Wierwille, 1979). See Green (1993) for an overview of experiments related to driving and measures of workload.

1. Primary Task Measurement

In a primary task measurement the operator performs a task, and some aspect of the task is varied to increase task loading (e.g., for steering a car, the mean and variance of a cross wind is increased). For the range of task loading where the operator maintains constant performance, the operator is assumed to have "spare capacity." Error and time, in this example lane position and speed, are therefore the dependent measures. These task measures tend to be sensitive to performance differences.

2. Secondary Task Measurement

In a secondary task measurement, the operator performs two tasks: the primary task, the operational task of interest (steering, for a car), and a secondary task which is imposed to occupy the part of the operator's "capacity" not required by the primary task (such as adjusting the car radio). Ideally, the operator maintains a constant level of performance on the primary task, and the workload level required for the primary task is inferred by comparing performance of the secondary task alone (such as the time to tune the radio) with the multitask situation. In this case, the secondary task is varied and therefore used as an indicator of the performance margin, or reserve, available above and beyond the performance requirements of the primary task.

However, superimposing a secondary task to measure workload requires careful experimental design. In situations of high workload, concurrent tasks (e.g., steering and using a navigation system) may interfere with each other and degrade the performance of one or more tasks. In addition, the capability to take on and complete new tasks (e.g., detect obstacles on the road) can be degraded because of overload or fatigue.

Dual task situations have been investigated in which driving has been paired with another task (e.g., Brown, Tickner, and Simmonds, 1969; Brown, Simmonds, and Tickner, 1967; Noy, 1989). The secondary tasks in these studies -- reasoning (e.g., a grammatical transformation task, which demands cognitive resources), visual search (e.g., finding a target line among distractor lines, which requires perceptual resources), a Sternberg task (memory resources), and interval production (motor resources) -- affected different aspects of driving. Driving and finding a target line among distractor lines produced decrements in some driving performance measures (decreased time to line crossing and increased standard deviation of lane position and velocity) (Noy, 1989). Driving with the reasoning task increased errors in judgments and decreased driving speed but did not affect other driving measures such as frequency of control use and lateral/longitudinal accelerations (Brown, Tickner, and Simmonds, 1969).

3. Physiological Measures

Several noninvasive physiological measurements are thought to measure aspects of operator state that correlate with the ability to perform tasks. Measures explored include transient and steady-state evoked cortical response (Donchin, 1981), heart rate and heart rate variability (Mulder, 1980), and rate of eye blinks (Stern, Walrath, and Goldstein, 1984).

4. Subjective Workload Measurement

In subjective workload measurement, the workload is what the subject reports it to be. To date, subjective measures have given the most consistent results. Subjective techniques range from ad-hoc surveys (the most widely used method) to highly formalized methods. The Cooper-Harper scheme for obtaining global pilot opinion ratings has become a standard for exploring aircraft flying qualities (Cooper and Harper, 1969). This method elicits a single opinion rating based on the operator's assessment of the performance achieved and the "compensation" (in effect, mental effort) required to achieve that performance. This method has been modified to apply to a broader range of tasks (Wierwille and Casali, 1983).

Other more recently developed structured schemes include SWAT (Subjective Workload Assessment Technique) developed for the Air Force (Reid, Shingledecker, and Eggemeier, 1981) and the NASA-TLX (Task Load Index) developed at NASA-Ames Research Center (Hart and Staveland, 1988). In SWAT, the operator provides a three-point rating on each of three dimensions (time load, mental effort, and psychological stress), whereas the NASA method elicits 20-point responses along six dimensions (mental demand, physical demand, temporal demand, performance, effort, and frustration). Both schemes yield a global workload rating from the individual ratings, and can distinguish between high- and low-workload tasks. The NASA scheme, however, is more sensitive and reliable for low-workload tasks (Battiste and Bortolussi, 1988).

5. Input Control

A strategy used in one of the classic studies of automotive workload research looks at primary task measurement by varying the information available to the driver, rather than varying aspects of the primary task. This particularly interesting method for assessing the attentional demand of driving was developed by Bolt, Beranek and Newman (Senders, Kristofferson, Levison, Dietrich, and Ward, 1967). Their method involved limiting the amount of time the driver could look at the road. A special helmet was developed which consisted of a mechanism to lower a translucent face shield (the type used on protective helmets) that occluded the driver's view of the road. (Research of this type is now conducted using special eyeglasses with LCD lens elements.) There were two experimental conditions: (1) the experimenter controlled lowering of the shield while the driver controlled vehicle speed, and (2) the driver controlled the shield while the speed was constant. Such a design allowed the experimenters to examine driver behavior in terms of information processing and uncertainty by quantifying the driver's need to see the road. The driver's need for visual information was interpreted as a reflection of workload.

Comparison of Alternative Measures

The number of experiments that specifically address the workload of driving is quite limited (Stephens and Michaels, 1964; Hendy, 1990; Green, 1993; Verwey, 1993). Hicks and Wierwille (1979) performed a study to examine the merits of alternative methods of empirically assessing the workload of driving. Students in a driving simulator experienced varying levels of workload on a primary task -- driving in differing levels of simulated crosswind. Five sets of secondary task measures were collected from subjects: (1) digit-reading performance (first done alone and then performed concurrently with driving); (2) heart-rate variability; (3) ratings of the effects of crosswinds for each session (A = extremely harsh and troublesome, K = extremely small or imperceptible); (4) ratings of attentional demand (A = extremely high attention needed, K = extremely low attention needed); and (5) an occlusion level, where the road scene was presented for 200 ms upon request by the driver.

Workload was defined as:

100 * (1 - (dual task performance / single task performance))

Workload variation led to significant differences in all measures of primary task performance, with steering wheel reversals being more sensitive than lateral variation which in turn was more sensitive than yaw deviation. Of the secondary tasks, only rating-scale data reflected the differences in workload (crosswinds location). There were no differences between the two ratings obtained. Digit reading performance, heart-rate variability, and occlusion times were not affected by workload. As Hicks and Wierwille explain, there were many possible reasons why these measures did not show significant effects, such as lack of experience with the equipment, small sample sizes, etc. For example, when the occlusion method was used, participants were willing to traverse more of the lane than they might have for a real road; perhaps there was an awareness of the lack of real risk of collision in the simulated condition.

From these results, Hicks and Wierwille recommend "primary task measures and rating scale measures should be used in assessing driver workload, particularly if it is of a psychomotor nature." (Hicks and Wierwille, 1979, p. 142). Their primary measures (steering-wheel reversals, yaw deviation, lateral deviation, rating scale values) were of attentional demand. The particular measures selected for each context require some thought. In this experiment, people were driving on a basically straight road and their course was perturbed by wind gusts. The immediate effect of such is to cause the vehicle to yaw suddenly, not move laterally, and hence yaw angle should reflect workload, as it did in the experiment. Further, the effects of crosswinds in driving are felt (as a torque on the steering wheel) before they are seen, but it is unclear what force feedback cues were provided in the simulation.

Computation of Driving Workload

One of the single most significant failings of the driving literature is the inability to compare results from one experiment with those of another. This is particularly important for today's IVHS (Intelligent Vehicle Highway Systems), where the usability of various devices (navigation systems, cellular phones, collision warning systems) are of interest. For example, suppose an experiment was conducted in Sweden on a "lightly traveled four-lane road," to examine the ease of use of a cellular phone. Must research attempting to build upon the work be conducted on the very same road to be valid? Can the work be replicated in a simulator? To make such decisions and allow comparisons of similar research, a method is needed to be able to characterize and quantify the relative difficulty of the driving task.

Based on an analysis of the literature, Hulse, Dingus, Fischer, and Wierwille (1989) proposed a first attempt to define driving workload, denoted as Q. Q is equal to the equation shown below, and has a range of values from 0 to 100 inclusive.

$Q = 0.4A + 0.3B + 0.2C + 0.1D$, where:

$A = 20 \log2(500/Sd)$ **(Sight Distance Factor)**

where Sd = sight distance (m)
if $Sd > 500$, then $A = 0$
if $Sd < 15.6$, then $A=100$

$B = (100*Rmax) / R$ **(Curvature Factor)**

where R = radius of curvature
$Rmax$ = maximum value of the radius of curvature
(set to 18.52 m (60.7 ft), the turn radius for a city street)

note: $R = 360X / (2\pi a)$
X = arc length along the curve (m)
a = change in direction (degrees)

$C = -40So + 100$ **(Lane Restriction Factor)**

where So = distance of closest obstruction to road (m)
(phone pole, fence, ditch, etc.)
if $So > 2.5$, then $C=0$

$D = -36.5W + 267$ **(Road Width Factor)**

where W = road width for 2 lanes (m)
if $W > 7.3$ (24 ft, 12 ft lanes), then $D = 0$
if $W < 4.57$ (15 ft, 7.5 ft lanes), then $D = 100$

Five graduate students studying human factors engineering at Virginia Polytechnic Institute, well acquainted with the concept of attentional demand, participated in an experiment to validate the measure. They were shown a map of the route and then drove it twice, once to become familiar with it and a second time to rate it on a scale of 1 to 9. Ratings considered the extent to which drivers could look away from the road, the possibility of unanticipated traffic, intersections, and interactions with other vehicles. Specifically, 1 corresponded to being able to look away from the road for long periods (4 s or more), 5 was for being able to look away for periods of 1 to 1.5 s, and 9 corresponded to not being able to look away at all. Correlations of the ratings and workload predictions were reasonably high.

Summary of the Literature

There is a body of literature on workload research, but much of it is for aircraft or aerospace applications. Not only is there a lack of understanding regarding the ability to transfer these results to the automotive industry, but there is no clear characterization of driving research to allow transfer of results from one road test to another, or from one driving simulator to another. Most of the automotive research to date has been conducted using secondary task methods to measure workload, yet it has been shown that primary task performance is the most sensitive indicator. There is clearly a need to be able to use physical descriptions of the world, especially the road, traffic conditions, time of day, etc. to identify the difficulty of the driving situation being examined. This report describes one attempt to do just that and to characterize road geometry as it affects workload.

Purpose of This Study

Two issues were investigated:

1. What are some representative driver performance data (e.g., speed and lane variance) for the UMTRI driving simulator as a function of road geometry?

2. What is the relationship between road geometry, subjective workload ratings, and predictions from Wierwille's model?

TEST PLAN

In this pilot experiment, eight people drove the UMTRI driving simulator for six sets of roads (varying in sight distance), each set having five road segments of varying width. The six sets were presented in a counterbalanced order; but the five road segments driven in each set were presented in the same order for the given sequence. Dependent variables were the lateral position on the road and the vehicle speed for each set of roads. Subjective ratings of the "difficulty" of driving each segment were also made. These performance parameters were viewed as reflections of driver workload. Driver workload due to road characteristics was calculated using Wierwille's model to establish a value for driver workload. This was compared to performance measures in the simulation and the ratings of workload.

Test Activities and Sequence

First, the experimenter explained the purpose of the experiment and had the subject complete a biographical form and consent forms. Next, far visual acuity was checked using a Titmus vision device. After moving to the simulator, the subject adjusted the power seat and steering wheel tilt as he or she wished. Once the procedure was explained, the subject practiced driving the simulator on winding roads to become accustomed to this task. There were three practice runs, which lasted about 5 minutes. Participants were instructed to drive the simulator as if it were a real vehicle (e.g. drive in the right lane, obey the speed limit of 55 mph).

After the practice runs, the video camera and tripod were then moved behind the participant so that both the subject and the road scene could be recorded. Each participant completed six test blocks which consisted of five roads each. The order of sight distances was partially counterbalanced across subjects as shown in Table 1 to minimize the confounding effects of practice. There was a 30 second break between each block for the experimenter to save the data and enter the test conditions for the next block. The sequence of roads within blocks was the same for all participants, as shown in Table 2. During each segment, the experimenter asked the subject to rate, on a scale of 1 to 10 (1=very easy, 10=very difficult), the difficulty level of driving that road.

Table 1. Sight Distances for Each Test Block (ft).

Subject	Age, Sex	Block					
		1	2	3	4	5	6
1	older male	480	1140	330	150	660	810
2	older male	330	150	660	810	480	1140
3	younger male	660	810	480	1140	330	150
4	older female	810	480	1140	330	150	660
5	younger female	1140	330	150	660	810	480
6	older female	330	150	660	810	480	1140
7	younger male	150	660	810	480	1140	330
8	younger female	810	480	1140	330	150	660

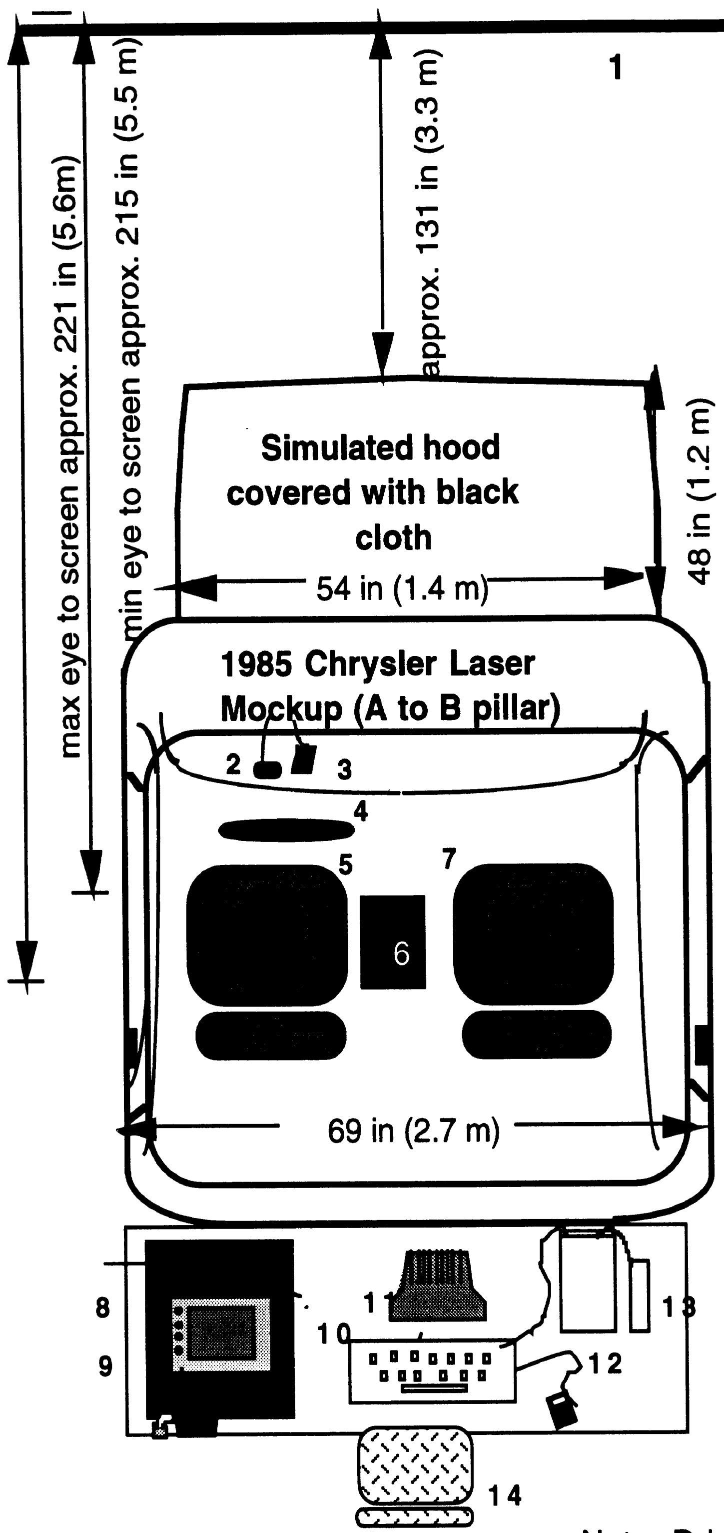
Table 2. Sequence of Roads within Blocks

Segment	Road	Width (ft.)
1	D	22
2	E	24
3	C	20
4	A	15
5	B	18

Test Materials and Equipment

This experiment was conducted using the UMTRI driving simulator (MacAdam, Green, and Reed, 1993) which includes a full size mockup of a car. A truck body was not used because one was not available. The use of a car body instead of a truck to estimate road-related workload should prove to be an inconsequential difference.

The simulator consists of a Macintosh Quadra 800 computer with a cache card, an overhead projector, an LCD projection panel, and an A-to-B pillar mockup of a 1985 Chrysler Laser, as well as custom written software. A 4 by 4.5 ft (1.2 by 1.4 m) cardboard sheet draped in black cloth was added to simulate the hood. The steering wheel, brake, and accelerator positions were all sensed by the Quadra. The image was projected onto an 8 x 12 ft (2.4 by 3.7 m) screen located approximately 20 feet (6.1 m) from the driver. Figure 1 shows the arrangement of the equipment and model numbers.



1- Free-standing wall covered with 3M Hi-white encapsulated reflective sheeting (8x12 ft)
2 - Brake pedal
3 - Accelerator
4 - Steering wheel
5 - Driver's power bucket seat
6 - Arm rest
7 - Passenger's seat
8- Sharp LCD computer projection panel, model QA-1650
9 - Custom stand for projector
10- Buhl overhead projector, model 2916
11 - Apple 13 in hi-resolution RGB monitor, M0401
12 - MacIntosh Quadra 800, (24 MB RAM, 200 MB hard drive); Apple extended keyboard II, M3501; Apple mouse II, M2760
13- Bernoulli 90 MB Mac transportable drive, model B190TM
14 - Experimenter's seat

Note: Driver's eyes are 21 in from left edge, 13.5 in left of car centerline.

Figure 1. Driving Simulator

A sample image shown to the driver appears in Figure 2. Speed is shown to the nearest mile per hour on a simulated HUD. Road characteristics that were specified include the heading and slope of each 30 foot (9.1 m) segment. Details on the roads appear in the appendix. Road segments had signs, trees, posts, and other objects next to them. All intersections were at right angles and only two-lane roads were presented. The screen update rate depended on the number of objects in the scene and the sight distance specified, though rates of 15-20 Hz were commonly used. Data were recorded each time the screen updated. Dependent measures included longitudinal and lateral position on the road, yaw angle, and vehicle speed.

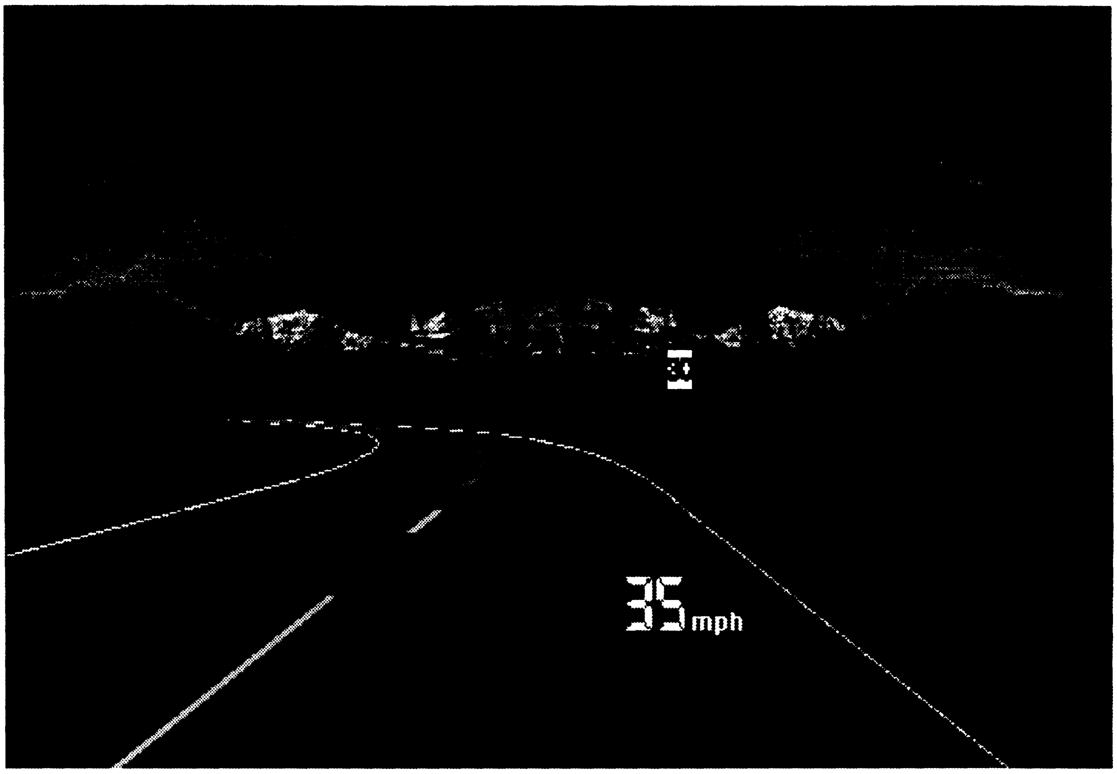


Figure 2. A sample road section

The simulated vehicle weighed 3215 lb (split 43/57 among the front and rear wheels) and had an 8.4 foot (2.6 m) wheel base. The front and rear cornering stiffness were 150 pounds/degree and 225 pounds/degree, respectively. The yaw inertia was 1500 slug-ft^2. The driver eye height was set at 42 inches (1.1 m). Steering resistance was provided by springs and bungee cords attached to the steering column.

Sessions with selected participants were recorded using a Hitachi model VM-H38A 8 mm camcorder. Driver far visual acuity was checked using a Titmus model OV-7m vision assessment device (slide number 2, both eye lamps lit).

Copies of the forms used (consent form, biographical form, ratings collection sheet) appear in the appendix.

Test Roads

Within each block of trials, a fixed sequence of six winding road segments (one practice segment and five test segments) was presented. The order of sight distances for each block was counterbalanced across subjects.

The width of the five road segments varied from 15 to 24 ft (4.6 to 7.3 m). The roads consisted of a series of straight sections and curves of 1000, 1500, 2000, and 5000 ft (305, 457, 610, 1524 m) all fairly mild. There were no intersections or traffic present. Complete descriptions of each road appear in the appendix.

Table 3 shows the workload for the various road segments driven as estimated by Wierwille's model. The model does not identify how to calculate the workload of a series of road sections: either of multiple curves in a given road segment, or of curves and straight segments combined. Therefore, it was assumed that the workload of a series of straight and curved sections was the workload of each section weighted by its length. The curvature contribution of straight sections was assumed to be zero (B=0 for the straight segments). Since the speed was relatively constant, using either distance or time leads to the same estimate. While the workload associated with curvature was not identical for all roads, the differences were very small (ranging from 2.0 to 2.3 on a 0 to 100 scale). Also, the range of the Sight Distance Factor was limited (0.0 to 6.3) but not the range of the Width Factor (0 to 100). Thus, given the range of workload values selected, the effect of sight distance on driver performance and estimated workload was expected to be small or nonexistent, while large differences due to road width were expected.

Table 3. Workload values estimated from Wierwille's model

Sight Distance (ft)	Segment	Road	Width (ft)	A Factor Sight Distance	B Factor Curvature	D Factor Width	Q =.4A+.3B+.2C+.1D	
							Total	
150	1	D	22	69.0	2.3	22.2	30.5	
150	2	E	24	69.0	2.0	0.0	28.2	
150	3	C	20	60.0	2.3	44.5	32.7	
150	4	A	15	69.0	2.3	100.0	38.3	
150	5	B	18	69.0	2.2	66.7	34.9	
330	1	D	22	46.2	2.3	22.2	21.4	
330	2	E	24	46.2	2.0	0.0	19.1	
330	3	C	20	46.2	2.3	44.5	23.6	
330	4	A	15	46.2	2.3	100.0	29.2	
330	5	B	18	46.2	2.2	66.7	25.8	
480	1	D	22	35.5	2.3	22.2	17.1	
480	2	E	24	35.5	2.0	0.0	14.8	
480	3	C	20	35.5	2.3	44.5	19.3	
480	4	A	15	35.5	2.3	100.0	24.9	
480	5	B	18	35.5	2.2	66.7	21.5	
660	1	D	22	26.3	2.3	22.2	13.4	
660	2	E	24	26.3	2.0	0.0	11.1	
660	3	C	20	26.3	2.3	44.5	15.6	
660	4	A	15	26.3	2.3	100.0	21.2	
660	5	B	18	26.3	2.2	66.7	17.9	
810	1	D	22	20.4	2.3	22.2	11.1	
810	2	E	24	20.4	2.0	0.0	8.8	
810	3	C	20	20.4	2.3	44.5	13.3	
810	4	A	15	20.4	2.3	100.0	18.9	
810	5	B	18	20.4	2.2	66.7	15.5	
1140	1	D	22	10.5	2.3	22.2	7.1	
1140	2	E	24	10.5	2.0	0.0	4.8	
1140	3	C	20	10.5	2.3	44.5	9.3	
1140	4	A	15	10.5	2.3	100.0	14.9	
1140	5	B	18	10.5	2.2	66.7	11.5	

note: C=0 (no lane restrictions)

Test Participants

Eight drivers (four men and four women) participated in this experiment. There was an equal number of each gender in each of two age groups, under 35 and over 65. The education level of participants varied from some trade/tech school to graduate school degrees. All test participants were paid $15 for their time.

RESULTS

What Were Some Representative Driver Performance Data for the UMTRI Driving Simulator as a Function of Road Geometry?

Summary statistics were computed for each participant for each sight distance for each road width using custom software. Statistics included the mean and standard deviation of lateral position, speed, and yaw angle.

Drivers positioned the simulated vehicle close to the center of the lane. Figure 3 shows the lateral position of the driver's eye point as a function of road width. In the test vehicle, the driver's eye point is approximately 13.5 inches to the left of the vehicle centerline. Adding that amount to the lateral eye position placed the simulated vehicle in approximately the center of the lane for all road widths (of two lanes). (Using the sight distance-road width means, the correlation between road width and mean lateral position was 0.99.)

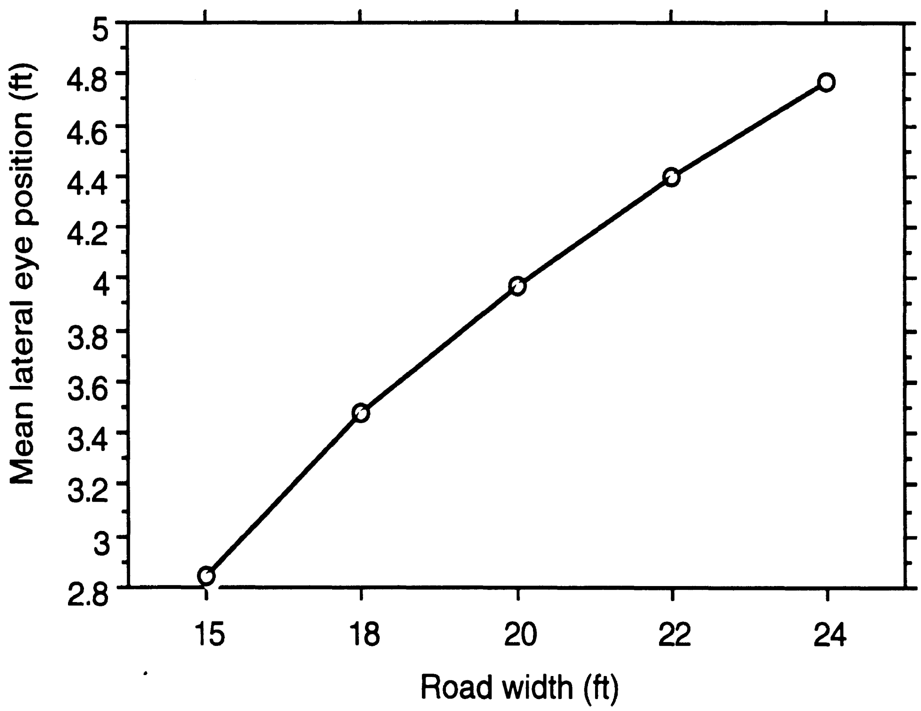


Figure 3. Effect of road width on mean lateral eye position.

An ANOVA of the means of the four main factors (road width, driver age, driver sex, and sight distance) showed significant differences in lateral road position due to road width ($F(4,189) = 136.30$, $p = 0.0001$) and driver age ($F(5,189) = 36.86$, $p = 0.0001$), but not sight distance ($p = 0.94$) or driver sex ($p = 0.87$). These results make sense. People drive in the middle of the lane, so lateral position should increase with road width. The goal of driving down the center does not change with sight distance, so mean lateral position should be unaffected by sight distance, as was the case here. It can be noted that there was, however, a significant age by sex interaction as shown in Figure 4. Given the small sample size, this interaction probably is just a reflection of individual differences.

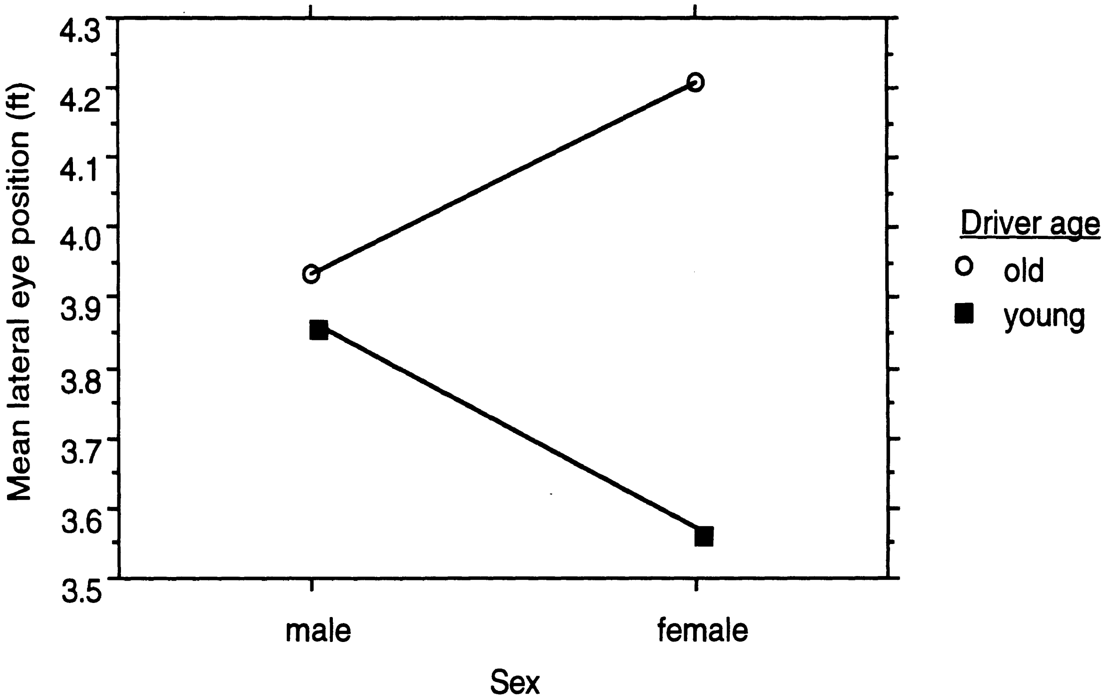


Figure 4. Mean lateral eye position - driver age by sex interaction.

When drivers departed from driving down the center of the lane, there was a very slight tendency to be left of center. Figure 5 shows the lateral eye position distribution for a 22-foot-wide road (11-foot lanes). (Again, the eye point is approximately 13.5 inches left of the vehicle centerline.) In general, drivers prefer to drive on the road (even in the other lane) than off it. That tendency is exaggerated in the simulator, which did not present oncoming traffic (to keep drivers in the lane) and a large number of curves (where drivers cut corners).

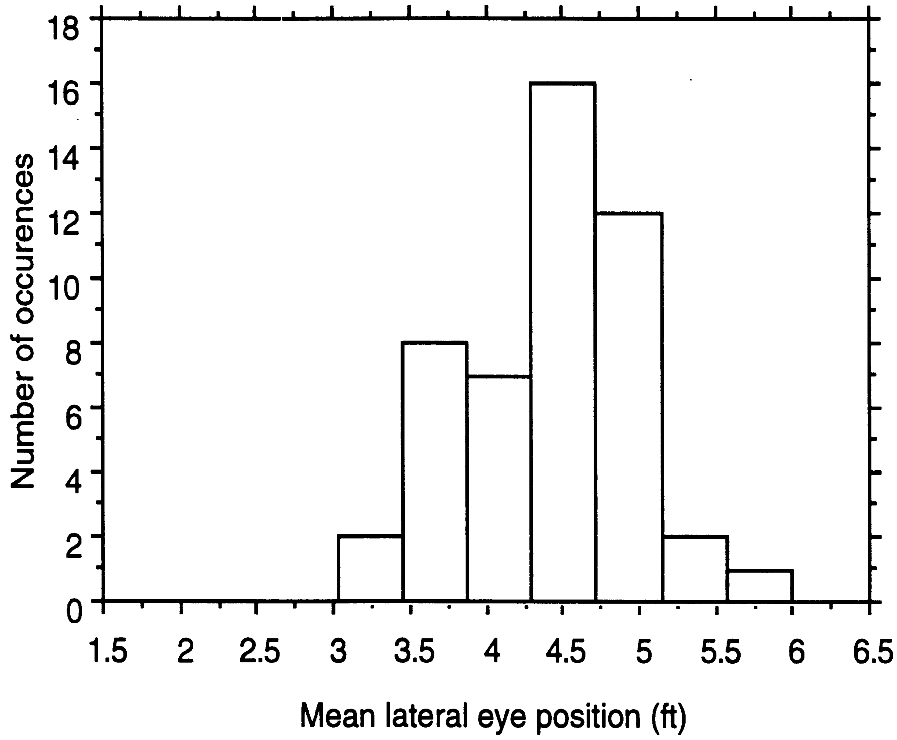


Figure 5. Mean lateral position for 22-foot wide road.

Figure 6 shows the distribution of lateral position averaged across all conditions. The standard deviation was 1.1 feet averaged across both straight sections and curves. In contrast, for data collected by an instrumented car on straight roads Green, Hoekstra, and Williams (1993) and Green, Williams, Hoekstra, George, and Wen (1993) report values of 0.5 feet as being typical.

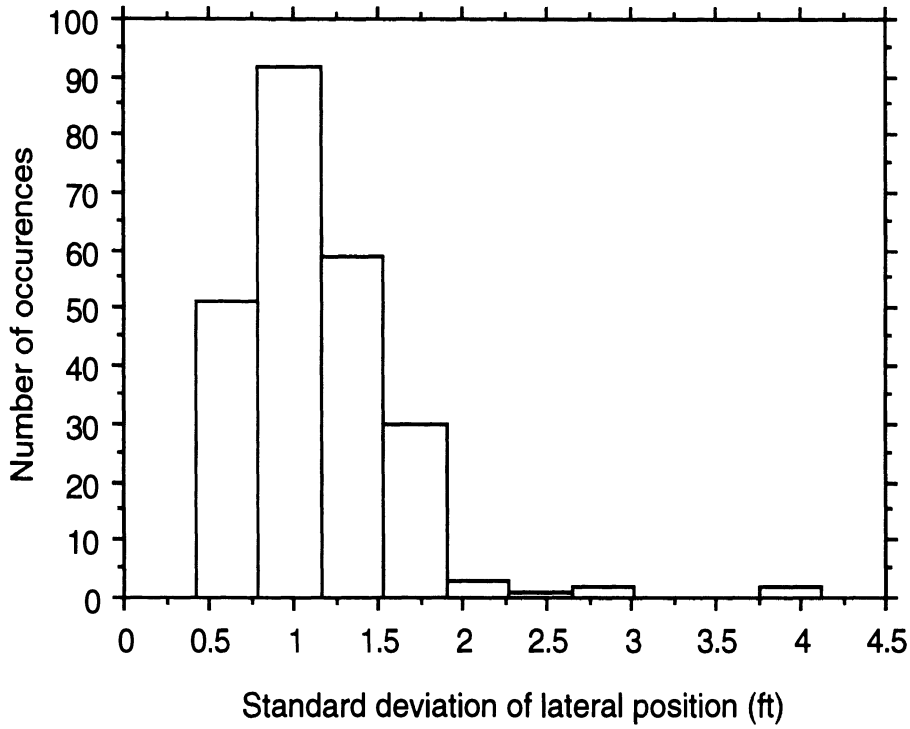


Figure 6. Standard deviation of lateral position.

An ANOVA of the standard deviation using the same four main factors revealed significant effects on lateral positioning due to road width ($F(4,189) = 11.23$, $p < 0.0001$), driver age ($F(1,189) = 12.91$, $p = 0.0004$), driver sex ($F(1,189) = 3.47$, $p < 0.0001$) but not sight distance ($p = 0.24$). In brief, when the road is wider, drivers tend to take advantage of the greater margin for error and are more variable in where they position the vehicle in the lane for straight sections (Figure 7). With greater sight distance, there is a slight tendency for drivers to reduce the variability in lateral position, most likely because there is more advance notice to plan the path (Figure 7). (In comparing Figures 7 and 8, notice that the vertical axis of Figure 8 is expanded.) Figure 9 shows the effects of age and sex, with younger drivers tending to be less variable in the lateral position. Given the small sample size, the differences shown in that figure primarily reflect individual driving styles.

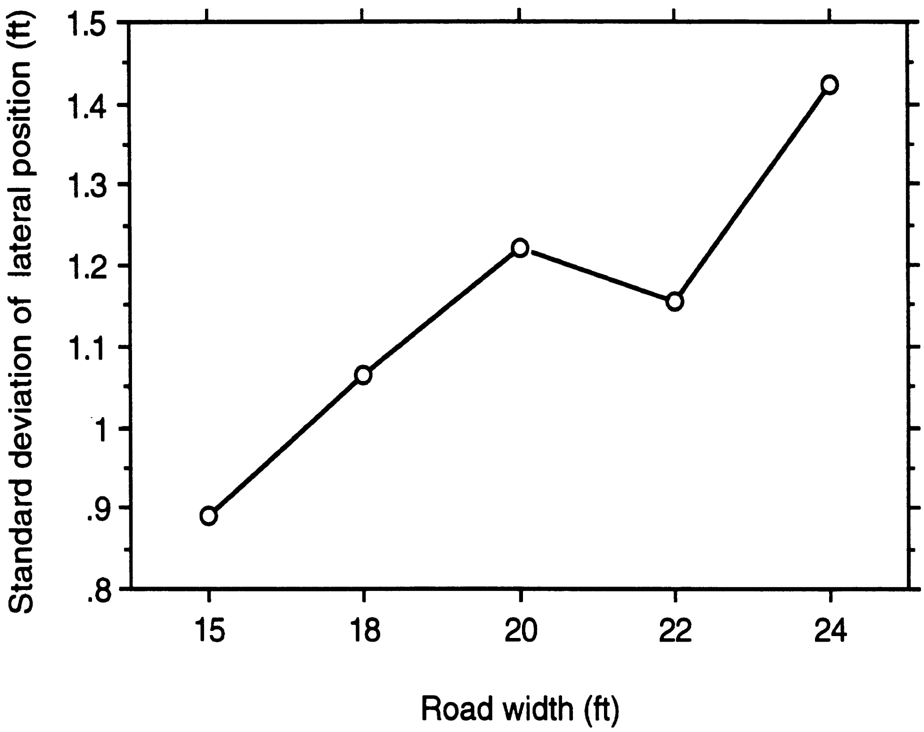


Figure 7. Effect of road width on the standard deviation of lateral position.
Note: Using the sight-distance, road-width means, r=0.44, p<0.05

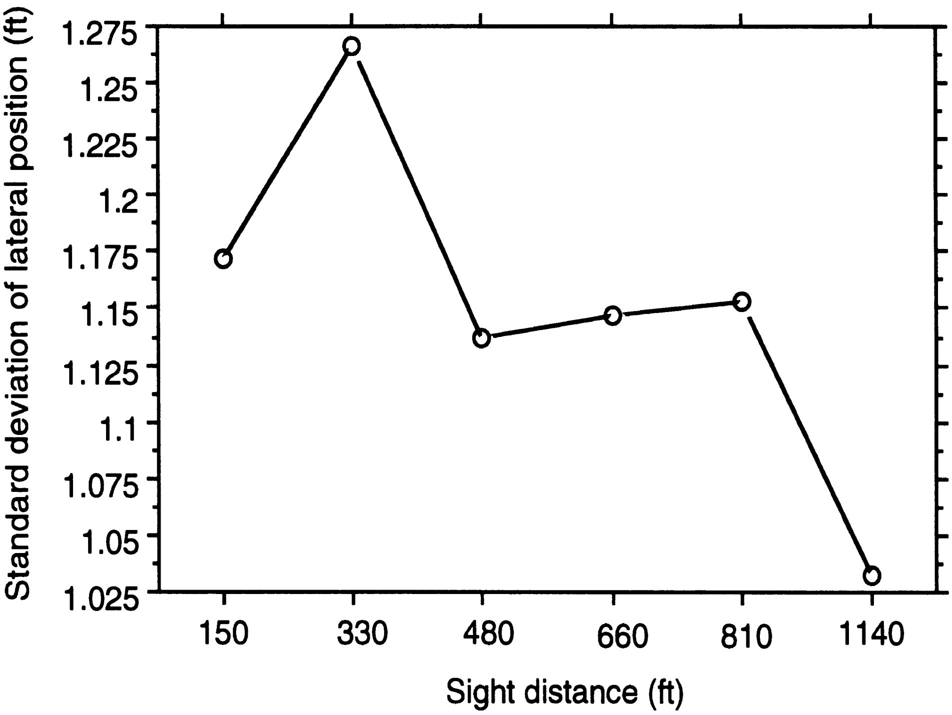


Figure 8. Effect of sight distance on the standard deviation of lateral position.

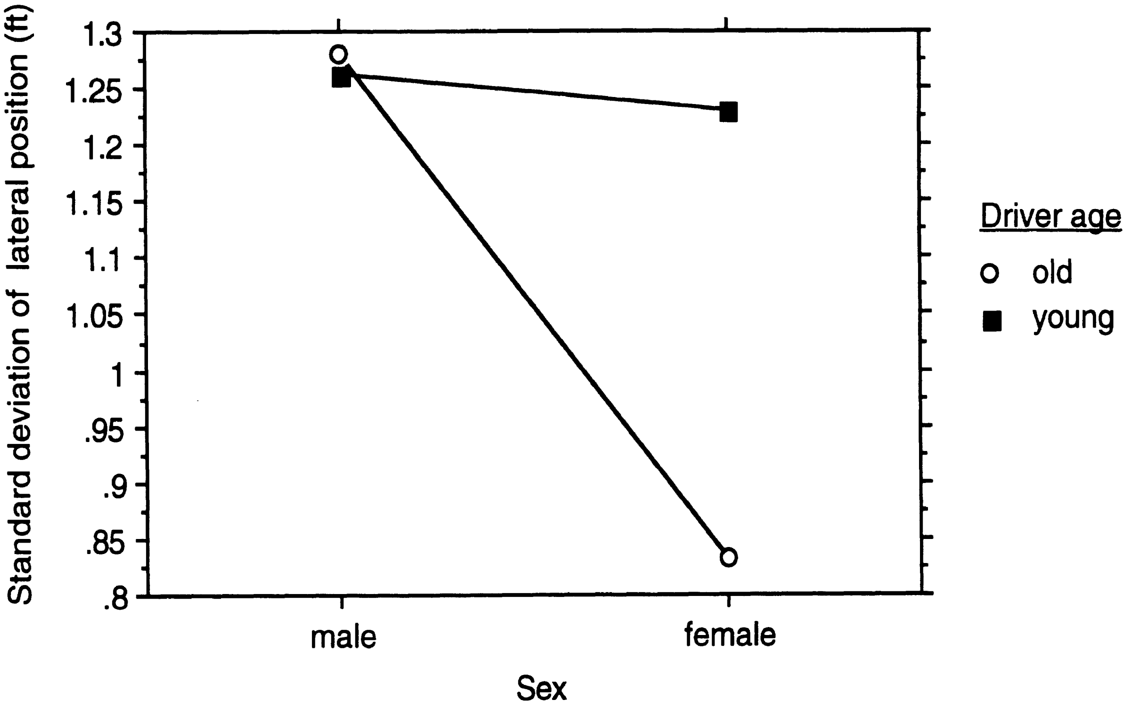


Figure 9. Effect of driver age and sex on the standard deviation of lateral position.

Figure 10 shows the independence of the relationship between road width and sight distance and their effects on the standard deviation of lateral position.

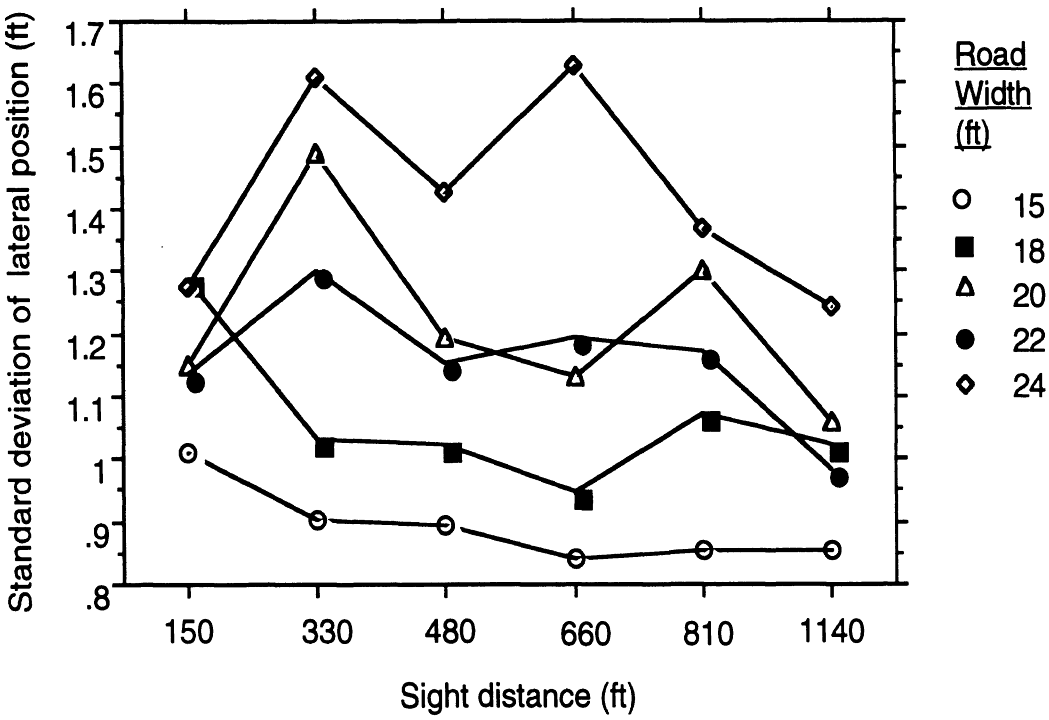


Figure 10. Effect of sight distance and road width on the standard deviation of lateral position.

The mean speed was 78.9 ft/sec (53.8 mi/hr), slightly less than the requested speed (55 mi/hr). Using the same main factors as before, an ANOVA of mean speed revealed only driver age and sex main effects were significant ($F(1, 189) = 57.37$, $p < 0.005$ and $F(1,189) = 208.19$, $p < 0.0001$ respectively). Figure 11 shows those individual differences in driving style. There was also a sight distance by sex interaction ($F(5,189) = 82.68$, $p < 0.05$). For some unknown reason women drove the road with the 150-foot sight distance as quickly as men and the 660-foot sight distance far more slowly.

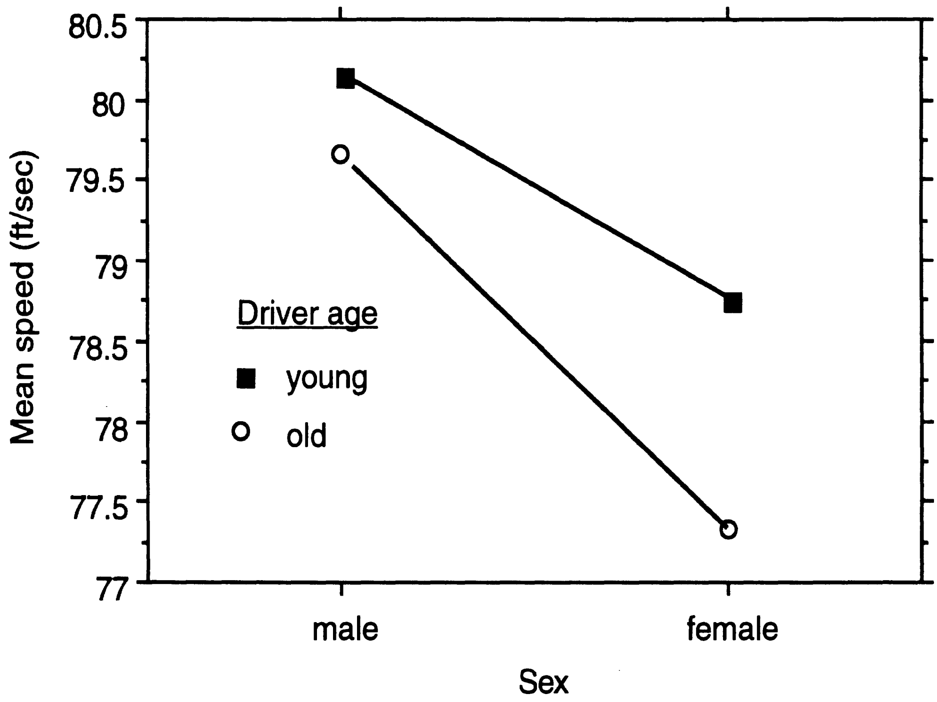


Figure 11. Effect of driver age and speed on mean speed driven.

The standard deviation of speed was exponentially distributed with a mean of 1.0 ft/sec (0.7 mi/hr). See Figure 12. For the standard deviation of speed only the effects of age and sex were statistically significant ($F(1, 189) = 11.95$, $p = 0.03$) and ($F(1,189) = 65.30$, $p < 0.0001$).

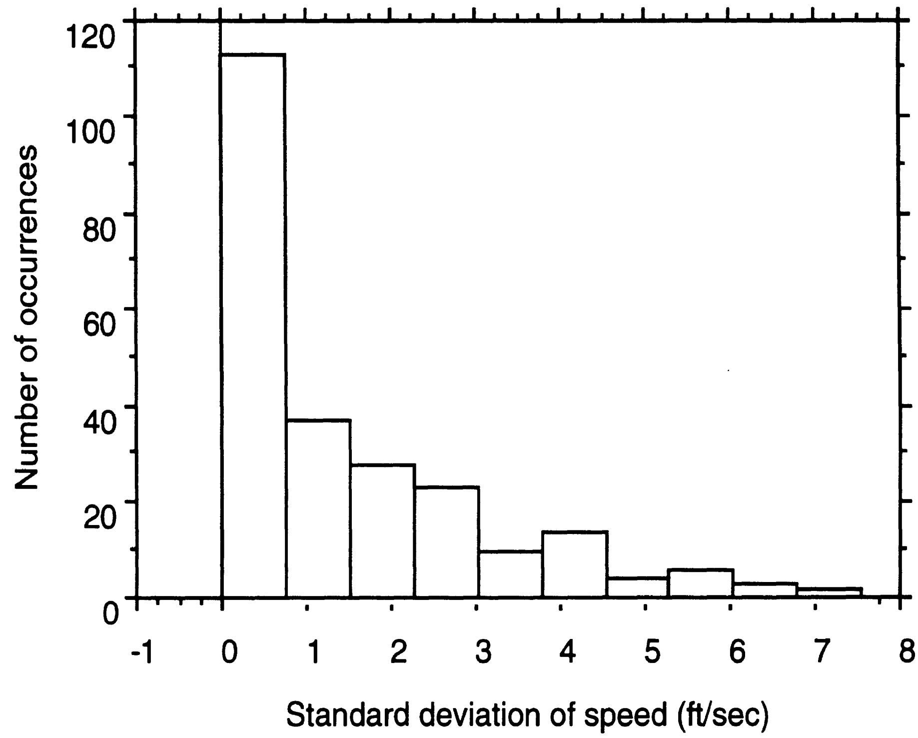


Figure 12. Standard deviation of speed.

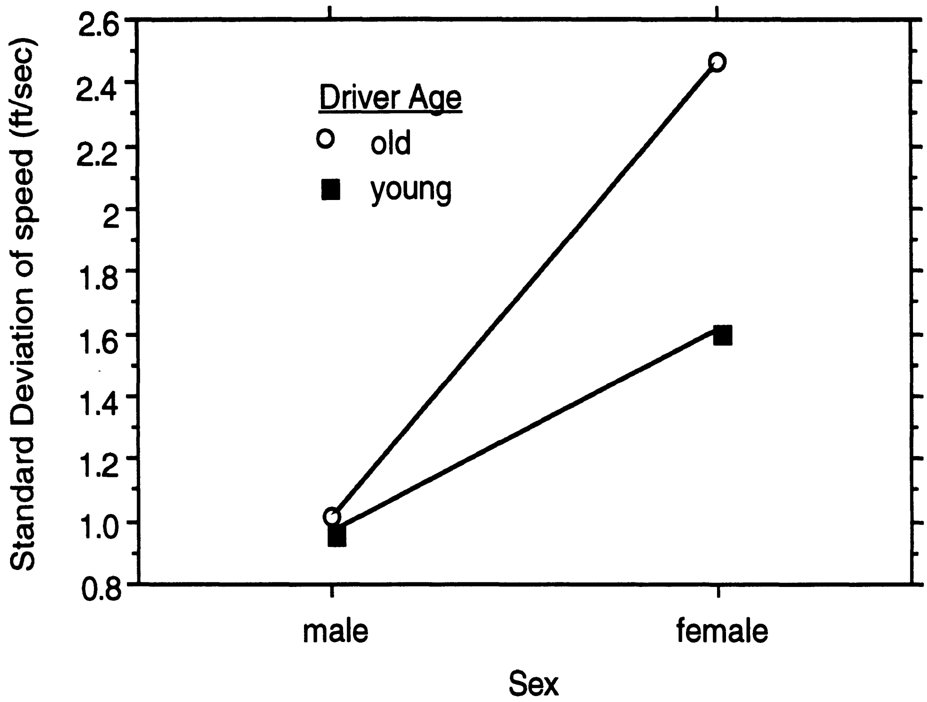


Figure 13. Effects of age and sex on the standard deviation of speed.

Yaw has not been explored in detail in the literature, primarily because it is difficult to measure accurately on the road. For this experiment, there were significant differences in yaw angle, with only road width being a significant effect in the model ($F(4,189) = 1.496$, $p < 0.0001$). This was the result of road curves not being uniformly distributed in each test segment. Similarly, there were significant differences due to the standard deviation of yaw on road width ($F(4,189) = 5429.51$, $p < 0.0001$).

Regression analysis showed that road geometry could be used to predict driver performance in only a few instances. Using the standard deviation of lateral position as the dependent measure, stepwise regression indicated that the standard deviation of lateral position = 0.12 + 0.5 (road width). This relationship accounted for 12% of the variance of the raw data. Adding sight distance did not significantly improve the prediction.

For predictions of mean speed, neither road width nor sight distance, when entered into the model, were statistically significant. Likewise, neither factor entered the regression model to predict the standard deviation of speed.

What Was the Relationship between Road Geometry, Subjective Workload Ratings, and Predictions from Wierwille's Model?

Table 4 shows the correlations of the various objective and subjective measures using the ratings for each road-width, sight-distance combination collapsed across drivers. Many of the mean and standard deviations of the performance measures were correlated with each other. In general, the correlation of the mean and standard deviation of yaw with other measures except for themselves, were lower than the correlations of other measures with each other. This suggests that yaw-related measures are less useful lateral performance measures than measures such as the standard deviation of lateral position. For that reason, yaw-related measures are not given much further attention in this analysis.

Table 4. Correlation of dependent measures across subjects.

	mean lateral position	sd lateral position	mean speed	sd speed	mean yaw	sd yaw	rating
sd lateral position	0.76***						
mean speed	0.42*	0.43*					
sd speed	-0.06	-0.05	-0.33				
mean yaw	-0.32	-0.48**	-0.07	0.37*			
sd yaw	0.33	0.48**	0.05	-0.34	-0.98***		
rating	-0.37*	-0.42*	-0.20	-0.18	-0.12	0.12	
Q	-0.43*	-0.14	-0.04	-0.11	0.15	-0.15	0.32

Note: * = $p < 0.05$
** = $p < 0.01$
*** = $p < 0.001$

The correlation between mean lateral position and the standard deviation of lateral positions was highly significant ($p<0.001$). (See Figure 6.) As noted earlier, the wider the road, the more of it drivers used, even though wider roads are less difficult to drive. It was been suggested that the standard deviation of lateral position is a potential measure of driving workload (Green, 1993), with greater standard deviation being associated with greater workload. As task demands increase, drivers pay less attention to driving steadily. These data suggest that the standard deviation of lateral position will be an imperfect indicator of workload if the road width varies across conditions.

Also significant was the correlation between the standard deviation of lateral position and mean speed ($p<0.05$). The faster participants drove, the greater the standard deviation of lateral position. Hence, driving faster was associated with less control over lateral position. (See Figure 13.)

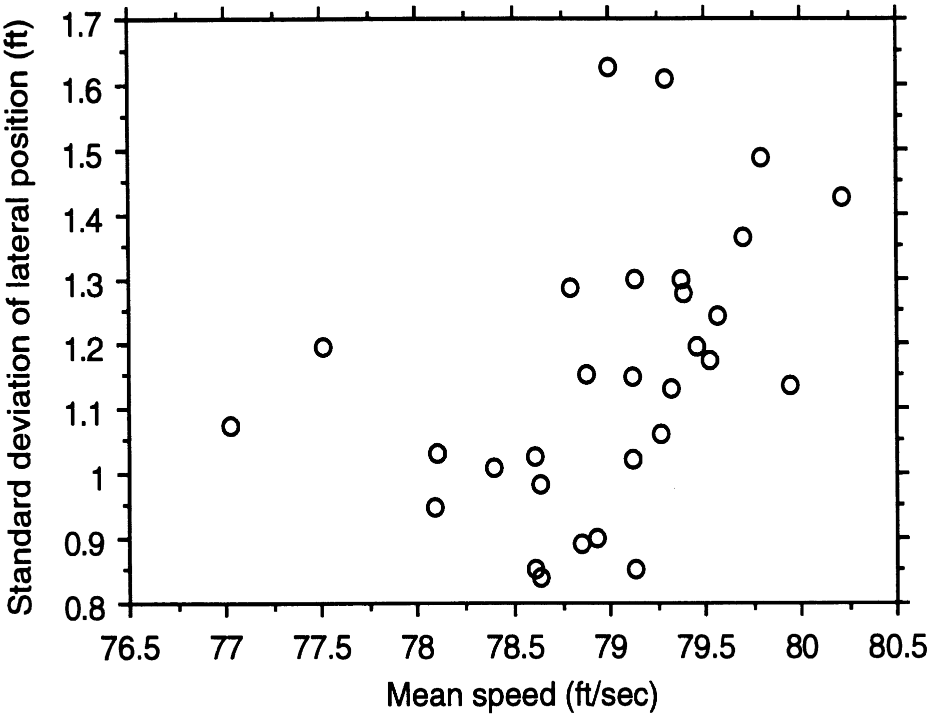


Figure 13. Correlation of mean speed versus standard deviation of lateral position.

Detailed Analysis of Subjective Workload Ratings

The subjective workload ratings were examined in a manner similar to the performance data. Figure 14 shows the distribution of the ratings. (1=very easy, 10=very difficult), with drivers tending to comment that most roads were easy to drive.

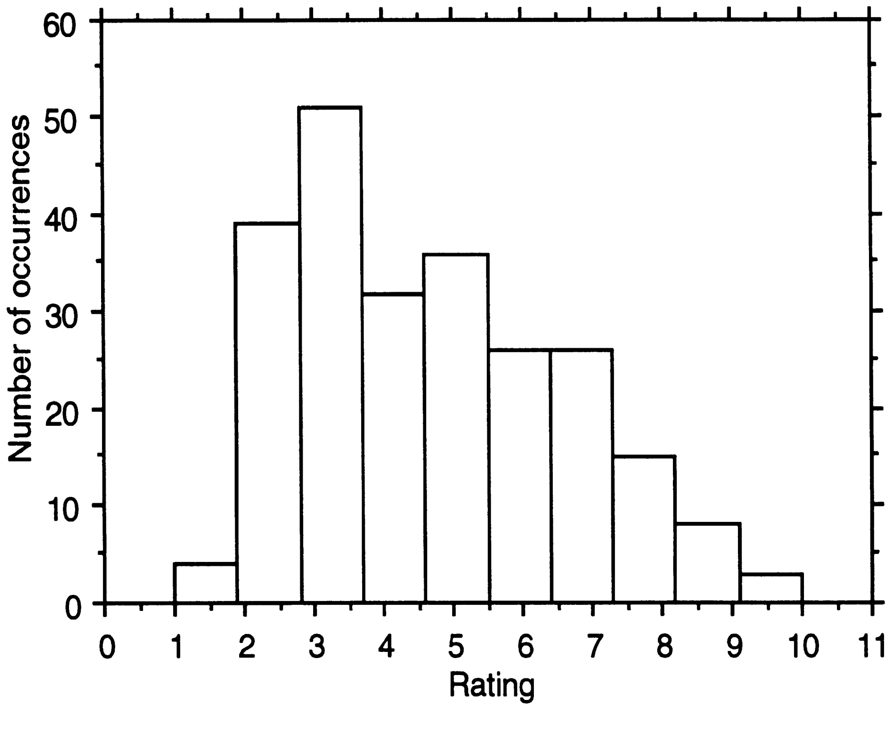


Figure 14. Distribution of workload ratings.

In the ANOVA of the workload ratings, driver age, driver sex, sight distance, and road width were the main effects. Also, in this instance, given the outcomes of the performance data analysis, only the age-by-sex interaction was included in the ANOVA model. Sight distance ($F(5,223) = 32.80$, $p < 0.0001$), road width ($F(4,223)$, $p = 0.007$), and the age-by-sex interaction ($F(1,223)$, $p = 0.004$) were all significant. Figure 15 shows the effect of road width. It is not clear why the 24-foot road was rated as more difficult than the 22-foot road. The 22-foot road actually had a slightly greater workload associated with it due to curvature as calculated with the Wierwille equation. Perhaps the 24-foot road, having a series of three curves at the beginning of the run, impressed the driver as being more difficult. Most likely, the fact that the 22-foot road (road D) was the first driven in each block affected the rating. The following road, the 24-foot width (road E) would seem to be easier, followed by a seemingly more difficult 20-foot road (road C) which may not have been that much more difficult than road E.

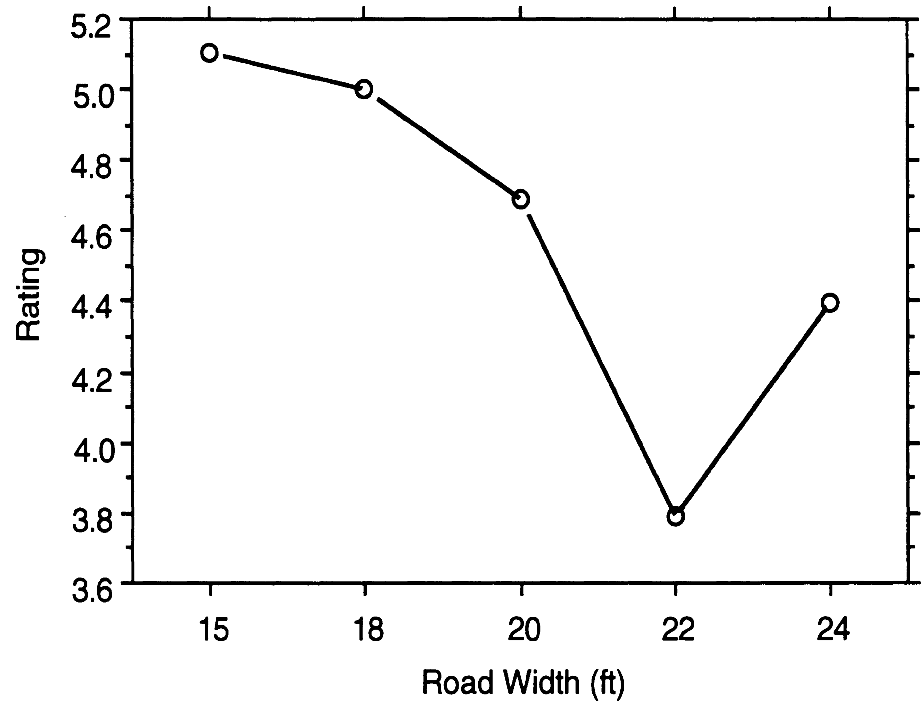


Figure 15. Effect of road width on workload rating.
Note: Using the sight distance-road width means collapsed across drivers, r=-0.37

Figure 16 shows the effects due to sight distance. Note the much wider range of the ratings for variations in sight distance. It was expected that workload would monotonically decrease with sight distance. (Large ratings of workload should be associated with short sight distances, but workload should be low for long sight distances.) It did not, even though the order of sight-distance conditions was partially, but not fully, counterbalanced across drivers. It may be that variations in the ratings are reflecting noise in the data.

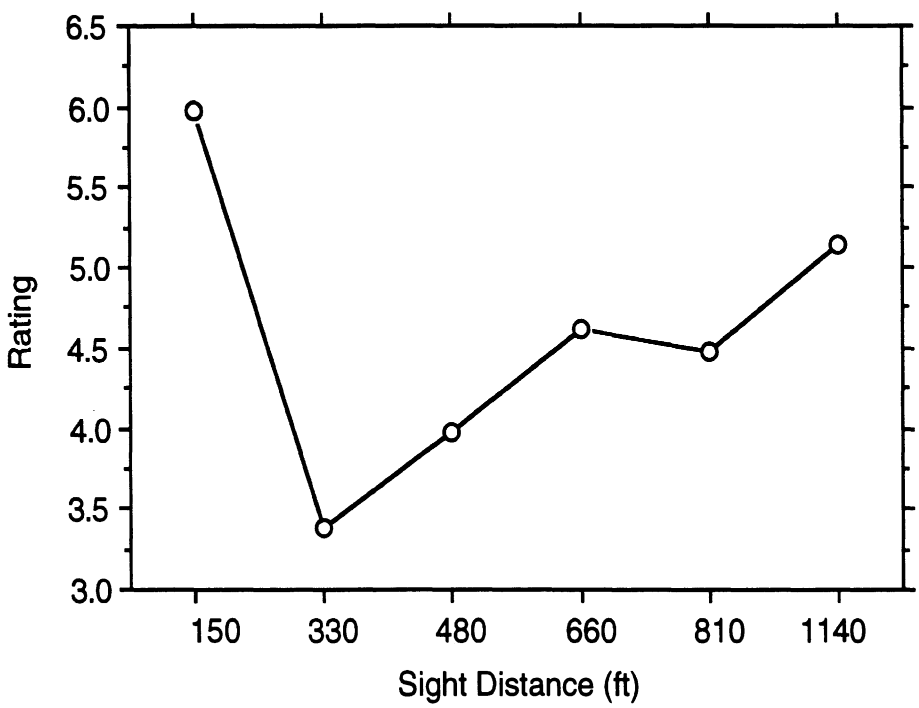


Figure 16. Effect of sight distance on workload rating.

Of considerable interest was the extent to which the various road-geometry measures would predict the workload ratings. Using the data from each road segment as input, a stepwise regression indicated that the workload rating = 6.93 - 0.12 (road width), (R^2 = 0.03), an outcome consistent with that given earlier using the means. Note that sight distance was not included in the model and this regression was based on the individual ratings. When the means (Figure 17) were used in place of the raw data, 61% of the variance was accounted for. Adding a second order term (road width squared) had no effect on the variance accounted for.

One possible explanation for the lack of strong correlations of workload ratings with sight distance and road width could be noise in the data (due to the limited number of drivers tested). Somewhat supporting this conclusion is the lack of correlation between the performance measures and the subjective workload ratings. Only the standard deviation of lateral position was correlated with the ratings (r=-0.42). One possible explanation for the lack of correlation was confounding due to road-width effects. As shown in Figure 18, collapsing the data across road width does not lead to a strong positive correlation.

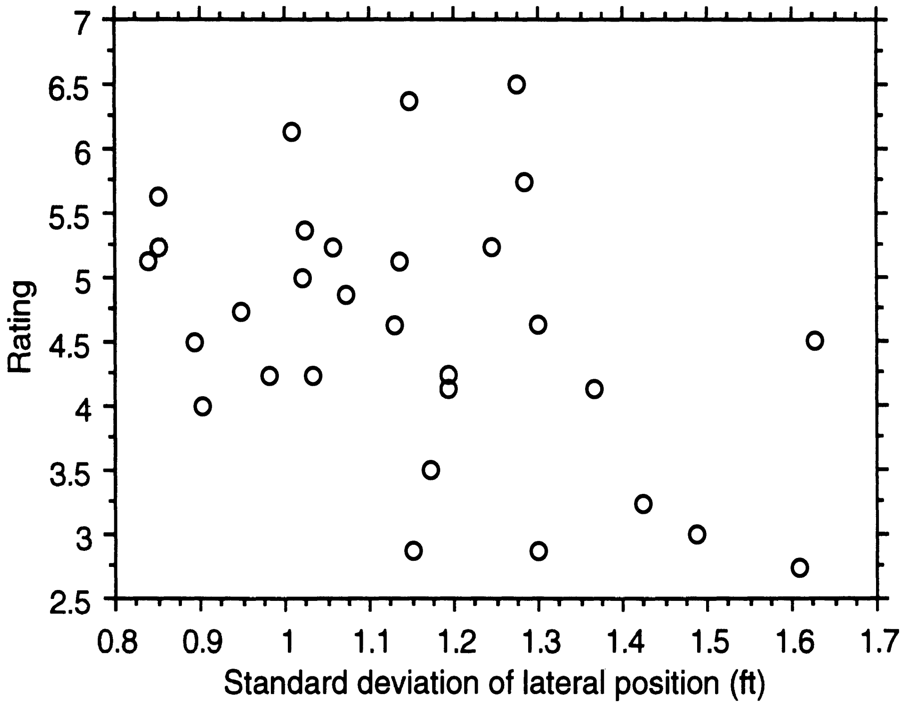


Figure 17. Relation of the standard deviation of lateral position to subjective workload ratings.
Note: Data are based on sight-distance road-width means.

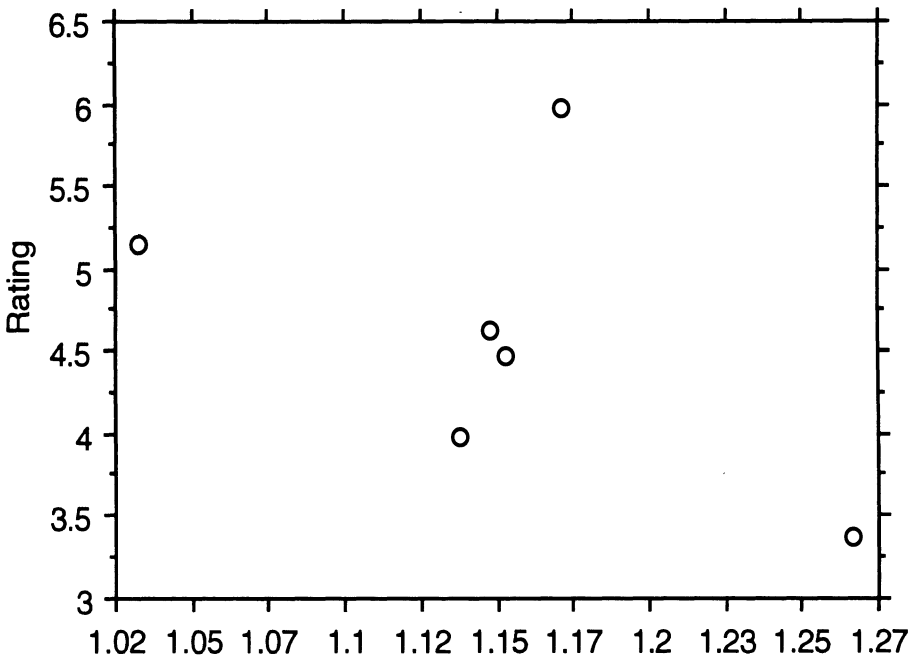


Figure 18. Relation of the standard deviation of lateral position to subjective workload ratings.
Note: Data are based on sight-distance means.

Also important were instances where correlations did not occur, namely between mean speed and the subjective ratings, and the standard deviation of speed and the ratings. (See Figures 19 and 20.) Presumably, the greater the workload, the slower people will drive and the more variable their speed will be, although some might suggest that the standard deviation of speed will decrease as mean speed decreases. The absence of correlations in this experiment is likely due to the instructions (drive at a constant speed) and the low driving task demands.

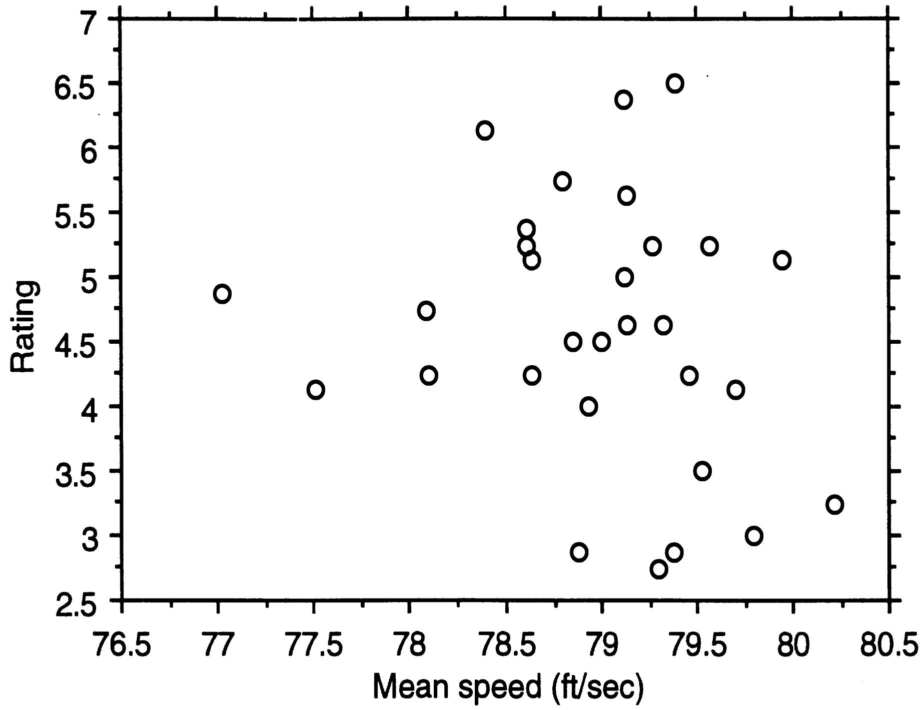


Figure 19. Relation of the mean speed (feet/sec) to subjective workload ratings.

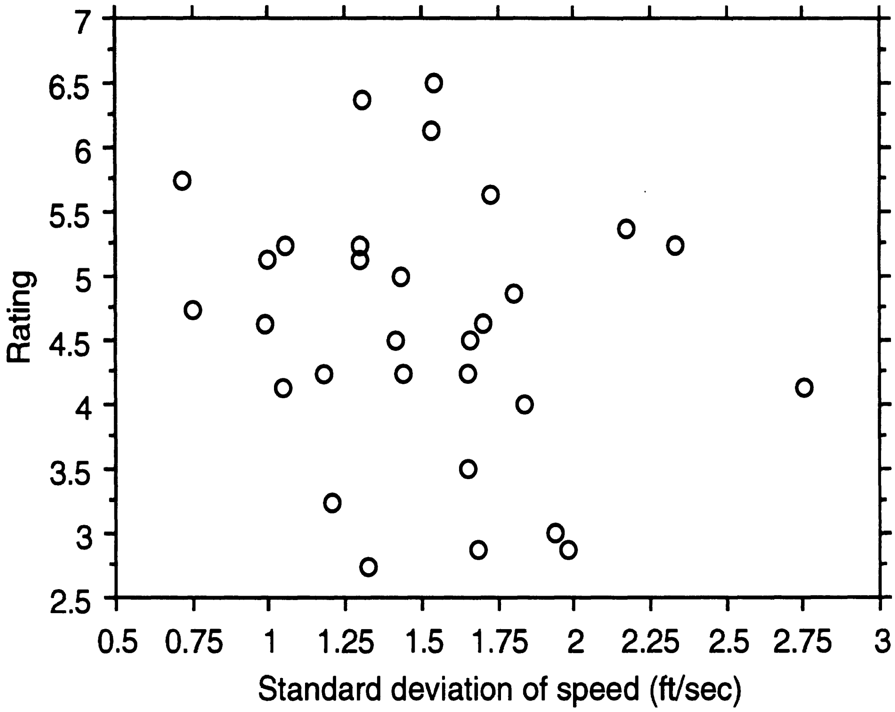


Figure 20. Correlation of the standard deviation of speed (feet/sec) with subjective workload ratings.

Detailed Analysis of the Wierwille Model Predictions

Figure 21 shows the relationship between the Wierwille estimates of workload (Q) and the mean subjective ratings of workload from the eight drivers. The correlation was not statistically significant (r=-0.32), though the trend was in the expected direction.

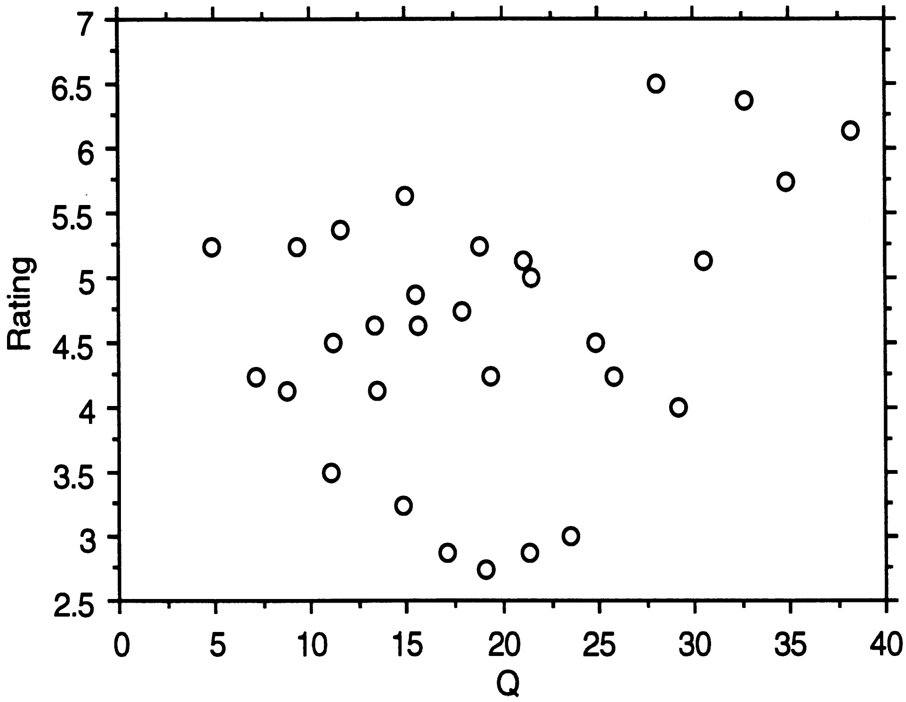


Figure 21. Correlation of workload predictions (Q) with subjective workload ratings.

Correlations of predicted workload (Q) with the driving performance measures were lower than those of the ratings with driving performance. None of the correlations were statistically significant, except for mean lateral position being negatively correlated with Q (r=-0.42). Wider roads (associated with larger mean lateral positions) had lower workload predictions. Figures 22, 23, and 24 show the relationships of workload predictions with the standard deviation of lateral position, mean speed, and the standard deviation of speed. Clearly there are no relationships in this data.

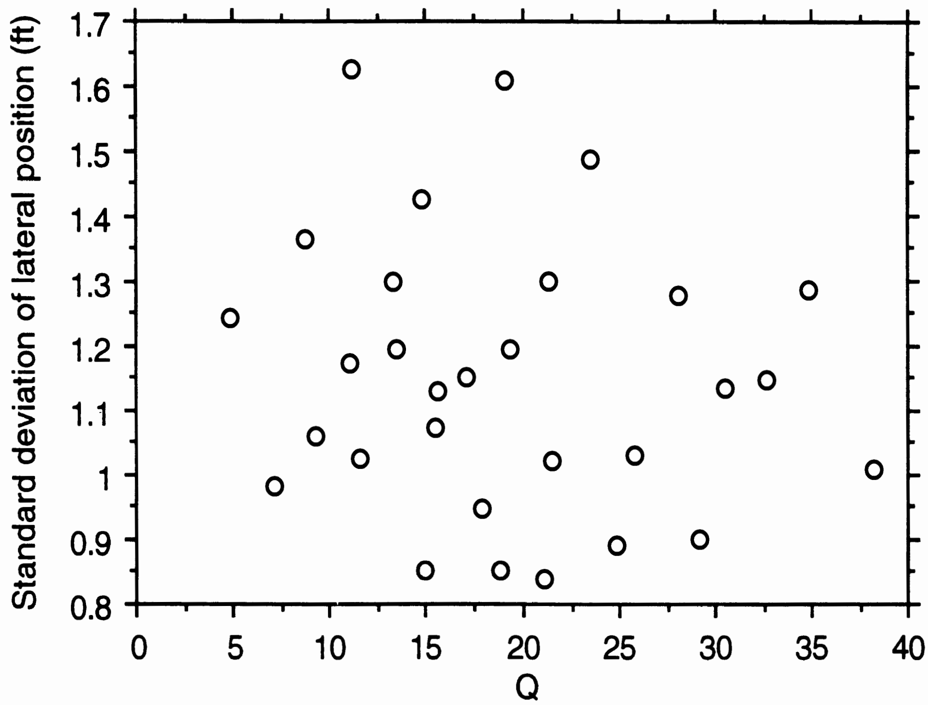


Figure 22. Relation of workload predictions (Q) to standard deviation of lateral position.

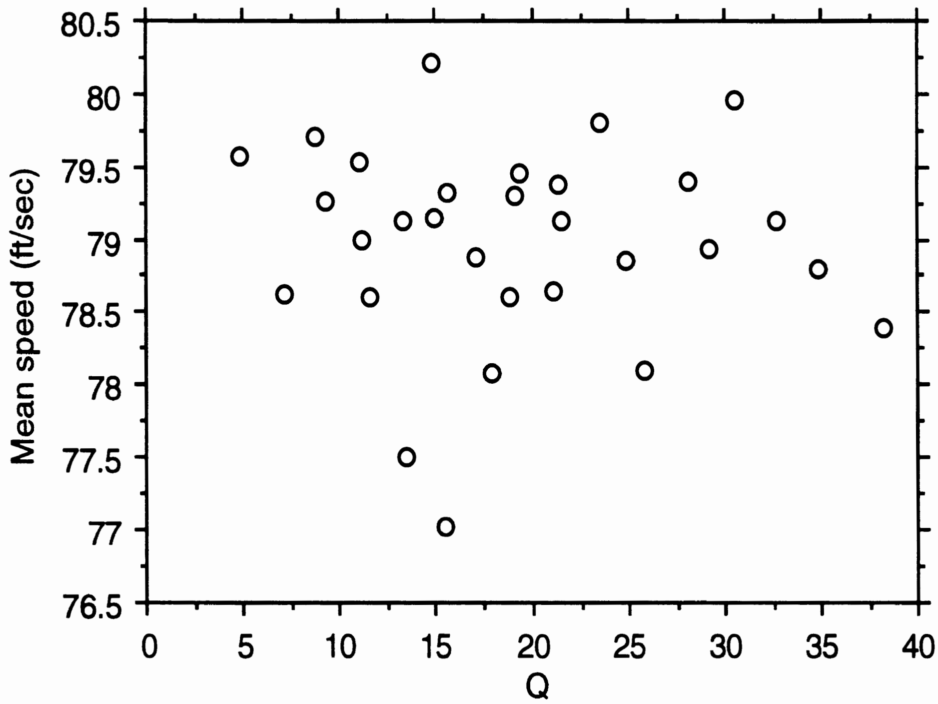


Figure 23. Relation of workload predictions (Q) to mean speed.

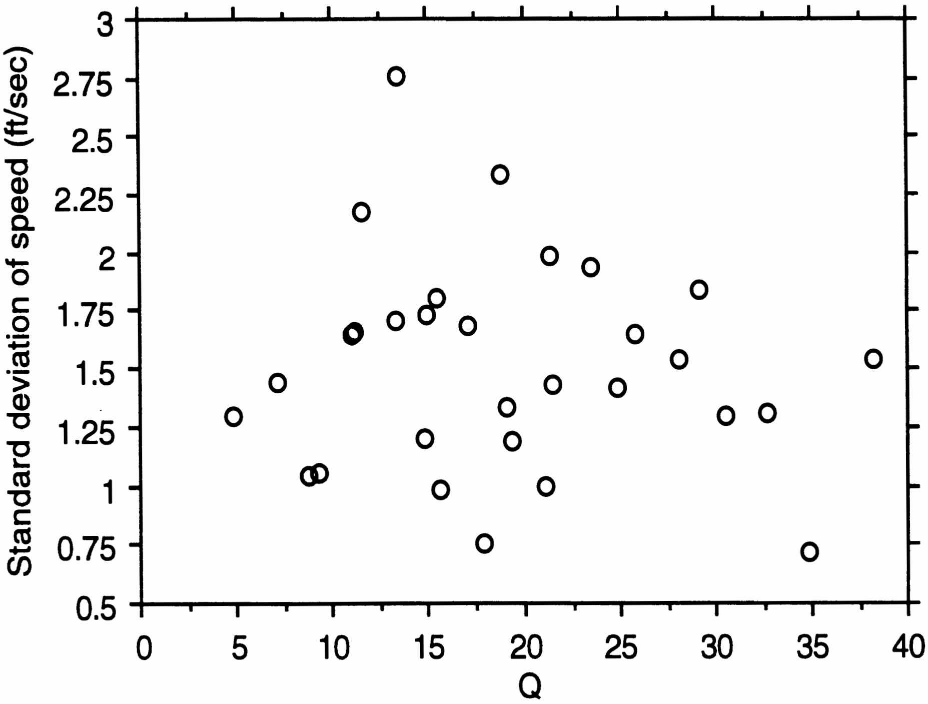


Figure 24. Relation of workload predictions (Q) to standard deviation of speed.

CONCLUSIONS

What Were Some Representative Driver Performance Data for the UMTRI Driving Simulator as a Function of Road Geometry?

Participants drove close to the center of the right lane, with a slight bias towards the center of the road. The bias most likely occurred because there was an implicit penalty for driving too far to the right (running off the road), but there was no penalty for driving too far to the left. (There was no traffic in the opposite lane.)

The standard deviation for simulator runs was 1.1 feet; which is somewhat greater than what has been reported for on-the-road experiments. The standard deviation increased as road width increased (0.9 feet for 7.5 foot lanes to 1.4 feet for 24 foot lanes), even though wider roads are associated with reduced workload. It appears that drivers utilized the road available, even when the consequence was increased standard deviation of lateral position. Hence, across road widths, lateral variance should not be used as a measure of workload.

The data for sight distance make limited sense. In general, increasing the sight distance decreased the standard deviation of lateral position, except for the 150-foot distance, which had a smaller standard deviation than the 330-foot sight distance. It is not apparent why this occurred. Overall, these data suggest that the greater the sight distance, the more time drivers have to plan maneuvers, which results in less lateral variation.

In general, the mean and standard deviation of speed did not correlate with the other driver performance measures, the subjective workload ratings, or the workload estimates from the Wierwille model. This may be because the speed was shown in a HUD directly in front of the driver and there were no external disturbances to alter vehicle speed. The driver merely held his or her foot in a fixed position, a very easy task.

What Was the Relationship between Road Geometry, Subjective Workload Ratings, and Predictions from Wierwille's Model?

Except for means and standard deviations of performance measures being correlated with each other, few measures correlated with each other or with subjective workload ratings of workload predictions, except for the standard deviation of lateral position being negatively correlated with workload ratings. This is because participants used more of the road on wider roads, roads for which the rated workload was less. Except for the 12-foot lanes, increasing road width led to rating the road as easier to drive. In the case of sight distance, the general pattern was for increasing sight distance to be associated with increases in ratings of workload. The 150-foot distance is an exception. Thus, the standard deviation of lateral position will prove to be an imperfect measure of workload if it is used for roads varying in width.

The workload ratings tended to reflect sight distance and road width effects, but not differences in driver performance. This could be due to the small sample, with correlations improving as the sample size is enlarged. Another explanation, which experimenters suspect for at least one subject, is that the rating anchors were reversed at times, with smaller values being given for greater workloads. It is also possible that because of the gamut of conditions, subjects were unable to remember the experience of the workload extremes, and consequently, rated the workload for each segment inaccurately. These problems can be eliminated by showing participants the workload extremes before the test session begins and by posting the rating endpoints in front of the participants at all times. There were also some minor differences in the roads used across conditions, varying slightly in the number of right and left curves (and hence the workload due to curvature). Estimates of subjective workload assume that total workload is a weighted linear sum of the length of each road segment. It may be that sections of higher workload, sections early in each session, or segments closest to the time when the estimate is requested contribute disproportionately to the workload estimate. Further work on aggregating workload estimates is needed.

In this experiment, the workload predictions did not appear to reflect driving workload as reported by the subjects. This could be because of the confounding effects of road width, and the ease with which speed could be maintained.

Final Remarks

Three key points emerge from this experiment. First, drivers use the road available to maneuver, so the standard deviation (influenced by lane width) cannot be readily used to assess workload across lane widths.

Second, steering performance is markedly affected by traffic, even if the traffic is stationary. Recently, the ability to display traffic has been added to the UMTRI driving simulator, and while there is no empirical data in hand, it is apparent from subsequent experience with the simulator that adding traffic increases the workload of the steering task. Drivers make a concerted effort not to wander into the opposite lane when traffic is in the opposite lane, something to which they do not give the same attention when traffic is absent, even if instructed to do so.

Finally, further thought is needed to determine how aggregate measures of workload should be computed: as a linear combination, or by weighting certain time periods more heavily, or certain difficulties differently.

It was initially expected that this experiment would confirm findings in the literature--that the driver performance measures correlated with subjective workload and predictions of workload. That did not occur, and while that may have been the result of minor flaws in the experimental protocol, these results suggest that there are reasons why the expected correlations will not always occur. These results are particularly important to those attempting to measure and predict driving workload, both for basic research, and for evaluating the attentional demand of new in-vehicle information systems.

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APPENDIX A - CONSENT FORM

Driver Workload

Participant Consent Form

The purpose of this experiment is to determine the effects of various driving conditions on the attentional demands of drivers. You will be seated in a driving simulator and a road scene will be projected onto a screen in front of you. The steering wheel, accelerator, and brake are fully functional, and the speedometer is also displayed so that you can monitor your speed at all times. You will be asked to drive the simulator as if you were driving a real vehicle and to obey traffic laws.

The experiment will take about 1 hour, for which you will be paid $15.00. If you have any problems or discomfort while participating in this experiment, you can withdraw at any time. You will be paid regardless.

A few of the sessions will be videotaped. Do you object to being videotaped?

yes   no

I have read and do understand the information above.

______________________	______________
Print your name	Date
______________________	______________
Sign your name	Witness (experimenter)

APPENDIX B - WORKLOAD BIOGRAPHICAL FORM

University of Michigan Transportation Research Institute
Human Factors Division

Subject: [ ]

Driver Workload Biographical Form

Date: [ ]

Name: ____________________

Male Female (circle one) Age: ________

Occupation: ____________________

Education: (circle highest level completed)

some high school	high school degree
some trade/tech school	trade/tech school degree
some college	college degree
some graduate school	graduate school degree

Other: ____________________
(If retired or student, note it and your former occupation or major)

What kind of car do you drive the most?

year: ________ make: ________ model: ________

Annual mileage: ________

Do you have any driving restrictions? yes no

If yes, please explain: ____________________

How often do you experience motion sickness while driving?

very often moderately often neutral seldom never

While flying?

very often moderately often neutral seldom never

While boating?

very often moderately often neutral seldom never

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	corrective lenses worn?
T	R	R	L	T	B	L	R	L	B	R	B	T	R	
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13	yes no

University of Michigan Transportation Research Institute
Human Factors Division

Subject: [ ]

Driver Workload Biographical Form

Date: [ ]

Name: ______________________________

Male Female (circle one) Age: __________

Occupation: ____________________

Education: (circle highest level completed)

some high school	high school degree
some trade/tech school	trade/tech school degree
some college	college degree
some graduate school	graduate school degree

Other: ______________________________

(If retired or student, note it and your former occupation or major)

What kind of car do you drive the most?

year: ________ make: ________ model: ________

Annual mileage: ____________

Do you have any driving restrictions? yes no

If yes, please explain: ______________________________

How often do you experience motion sickness while driving?

very often moderately often neutral seldom never

While flying?

very often moderately often neutral seldom never

While boating?

very often moderately often neutral seldom never

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	corrective lenses worn?
T	R	R	L	T	B	L	R	L	B	R	B	T	R	
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13	yes no

APPENDIX C - DRIVER WORKLOAD EXPERIMENT INSTRUCTIONS

Before subject arrives:
• Check schedule to determine subject name, number and designated starting point for experiment (according to counterbalanced ordering for starting sight distance).

• Laboratory Activities (if first subject of the day)
Simulator, Mac, monitor, OK
Have disk ready to save data.

• Set up Titmus vision tester in the conference room. Have ready a consent form, biographical form, payment forms (University employee or non-U employee), and $15.00 cash (if subject is not a University employee).

• Set up equipment needed to videotape the experiment (only needed for a few subjects) in the conference room. Place the video camera on a tripod and adjust it so that the experimenter and subject seated at the table can be recorded. Place an 8-mm tape in the camera and get ready to record.

• Set up simulator. Turn on computer and projector and get practice run ready. Make sure control buck is on. Have the Workload Ratings Collection Sheet ready, with order of sight distances filled out.

When subject arrives

Hi, are you _________ (use subject's name)**? I'm** _________ (experimenter's name). **Thanks for coming, let's go down to the conference room so we can begin.**

Take subject down to conference room and be seated.

As I mentioned earlier, this study will take about 1 hour to complete, and you will be paid $15.00. It involves using our driving simulator to drive road segments under various conditions.

The purpose of this experiment is to determine the workload of driving, that is, how difficult is it to drive, and how do varying road conditions affect driving performance .

Before we start, there is some paperwork to complete. First you need to read and sign this official consent form, which basically repeats in writing what I just said. I also want to mention that if you feel uncomfortable at any time in the experiment, you should let me know and we can stop. You will be paid regardless.

Have participant read and sign the consent form.

Also, we need to know a little more about you.

Go through bio form with subject and fill in the appropriate answers.

Now we can check your vision.

Turn on both eye switches on the vision tester, slide 1. Adjust the height of the vision tester for the subject. Make sure subject wears any vision correction that is worn while driving. Note on the bio form if corrective glasses were worn.

Can you see in the first diamond, that the top circle is complete but the other three (on the right, left, and bottom) are incomplete? Can you tell me which circle is complete in the second diamond? The third?...

Prompt the subject until s/he has missed two in a row. Record the last number answered correctly on the bottom of the bio form. Take subject to laboratory. If the session is being videotaped, bring the camera/tripod into the laboratory and place it in front of the simulator to record the next set of instructions. Start recording...

Please sit in the driver's seat of the simulator. The seat and steering wheel may be adjusted to make you more comfortable.
Show subject where seat controls and steering wheel adjustment are located. Experimenter sits at table to the rear of the simulator. Explain the procedure to subject:

Like I said before, the purpose of this study is to determine the workload of driving under various driving conditions. The road scene will be projected onto the screen straight ahead. The roads are winding, two lane highways, with no intersections. The simulator's steering wheel, accelerator, and brake are fully functional, so simply drive as you would a regular car. The speedometer is displayed on the screen, so you can monitor your speed at all times. Drive in the right lane and drive as carefully as possible, while trying to maintain a constant speed of 55 miles per hour for all roads. If driving at 55 makes you uncomfortable or affects your driving, drive at a slower speed.

You will be given a 5 minute warm-up to get used to driving the simulator. The warm-up consists of 3 practice runs. Once you are comfortable with it, you will begin the experiment. You will perform 6 trials, each of varying driving conditions. Each trial will last about 7 minutes, and you will have a break of about 30 seconds in between trials. Periodically throughout each trial, I will be asking you to rate the level of driving difficulty, on a scale of 1 to 10 (1=very easy, 10=very difficult). Do not hesitate to use the full range of the scale. You can tell me your rating aloud and I will record your responses.

Remember: If at any time during the experiment you feel uncomfortable, please let me know and we can take a break or stop the experiment.

Do you have any questions before we begin the study?

Place the camera behind the subject and aim it so that it will record the subject and the road scene.

For each trial:

• Select "Data" menu to create a new data file — type in the date, subject's name and number, and sight distance in the header.
• Select "Options" menu to set the sight distance
• Select "File" menu to open the appropriate world file — the practice runs used the world files called "world-warmup1," "world-warmup2," and "world-warmup3." The experiment used the "world-test" file.
• Select "Control" menu to run the simulator.
• Ask subject to rate the level of driving difficulty on a scale of 1 (very easy) to 10 (very difficult). The rating points are located near the end of each road and is designated by a small black post on the right side of the road.
• When finished with each trial, select the "Data" menu and flush data to disk to save the data.

OK, we're all done here. You may get out of the car now. We just need to finish up the paperwork for your payment and we'll be all finished.

At the table in the front of the lab, give participant the appropriate payment form . Show them the parts to fill out.

Make sure paperwork is filled out properly, and pay the subject (if not university employee). Otherwise tell participant that the amount will be on their next paycheck. Thank the participant and walk them back out to the third floor elevator of UMTRI.

<u>After Subject has left:</u>

Copy the data for that session off the Hard Drive onto the floppy disk.

If the last subject of the day, shut down Mac and other equipment. Be sure all the data for the subjects that day is backed up onto the floppy disk.

Now we can check your vision.

Turn on both eye switches on the vision tester, slide 1. Adjust the height of the vision tester for the subject. Make sure subject wears any vision correction that is worn while driving. Note on the bio form if corrective glasses were worn.

Can you see in the first diamond, that the top circle is complete but the other three (on the right, left, and bottom) are incomplete? Can you tell me which circle is complete in the second diamond? The third?...

Prompt the subject until s/he has missed two in a row. Record the last number answered correctly on the bottom of the bio form. Take subject to laboratory. If the session is being videotaped, bring the camera/tripod into the laboratory and place it in front of the simulator to record the next set of instructions. Start recording...

Please sit in the driver's seat of the simulator. The seat and steering wheel may be adjusted to make you more comfortable.
Show subject where seat controls and steering wheel adjustment are located. Experimenter sits at table to the rear of the simulator. Explain the procedure to subject:

Like I said before, the purpose of this study is to determine the workload of driving under various driving conditions. The road scene will be projected onto the screen straight ahead. The roads are winding, two lane highways, with no intersections. The simulator's steering wheel, accelerator, and brake are fully functional, so simply drive as you would a regular car. The speedometer is displayed on the screen, so you can monitor your speed at all times. Drive in the right lane and drive as carefully as possible, while trying to maintain a constant speed of 55 miles per hour for all roads. If driving at 55 makes you uncomfortable or affects your driving, drive at a slower speed.

You will be given a 5 minute warm-up to get used to driving the simulator. The warm-up consists of 3 practice runs. Once you are comfortable with it, you will begin the experiment. You will perform 6 trials, each of varying driving conditions. Each trial will last about 7 minutes, and you will have a break of about 30 seconds in between trials. Periodically throughout each trial, I will be asking you to rate the level of driving difficulty, on a scale of 1 to 10 (1=very easy, 10=very difficult). Do not hesitate to use the full range of the scale. You can tell me your rating aloud and I will record your responses.

Remember: If at any time during the experiment you feel uncomfortable, please let me know and we can take a break or stop the experiment.

Do you have any questions before we begin the study?

Place the camera behind the subject and aim it so that it will record the subject and the road scene.

For each trial:

APPENDIX D - WORKLOAD RATING DATA SHEET

WORKLOAD RATINGS COLLECTION SHEET

Subject name:
Subject #:
Date:

Trial #1
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #2
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #3
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #4
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #5
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #6
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

APPENDIX E - DESCRIPTION OF ROADS

Road A	Length (ft)	Type	Radius (ft)
	570	straight	
	450	curve	1500
	270	straight	
	510	curve	-2500
	270	straight	
	450	curve	1500
	240	straight	
	420	curve	2000
	270	straight	
	420	curve	-1000
	240	straight	
	450	curve	-2000
	300	straight	
	420	curve	1000
	540	curve	-1500
	30	curve	-5000
	30	curve	-2000
	690	straight	
Total	6570		
Road B	570	straight	
	420	curve	-1000
	300	straight	
	510	curve	-2500
	270	straight	
	450	curve	1500
	240	straight	
	480	curve	1000
	210	straight	
	420	curve	-1500
	240	straight	
	450	curve	2000
	300	straight	
	390	curve	2000
	150	straight	
	420	curve	-1500
	30	curve	-5000
	30	curve	-3000
	690	straight	
Total	6570		

APPENDIX D - WORKLOAD RATING DATA SHEET

WORKLOAD RATINGS COLLECTION SHEET

Subject name:
Subject #:
Date:

Trial #1
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #2
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #3
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #4
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #5
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

Trial #6
Sight distance:
Starting point: D

Segment	Road	Width (ft.)	Rating
1	D	22	
2	E	24	
3	C	20	
4	A	15	
5	B	18	

APPENDIX E - DESCRIPTION OF ROADS

Road A	Length (ft)	Type	Radius (ft)
	570	straight	
	450	curve	1500
	270	straight	
	510	curve	-2500
	270	straight	
	450	curve	1500
	240	straight	
	420	curve	2000
	270	straight	
	420	curve	-1000
	240	straight	
	450	curve	-2000
	300	straight	
	420	curve	1000
	540	curve	-1500
	30	curve	-5000
	30	curve	-2000
	690	straight	
Total	6570		
Road B	570	straight	
	420	curve	-1000
	300	straight	
	510	curve	-2500
	270	straight	
	450	curve	1500
	240	straight	
	480	curve	1000
	210	straight	
	420	curve	-1500
	240	straight	
	450	curve	2000
	300	straight	
	390	curve	2000
	150	straight	
	420	curve	-1500
	30	curve	-5000
	30	curve	-3000
	690	straight	
Total	6570		

Road C	570	straight	
	450	curve	1500
	270	straight	
	480	curve	-2000
	270	straight	
	480	curve	-1000
	240	straight	
	450	curve	2000
	240	straight	
	390	curve	-1500
	270	straight	
	450	curve	1000
	270	straight	
	420	curve	1500
	180	straight	
	390	curve	-1500
	30	curve	-6000
	30	curve	
	690	straight	
Total	6570		
Road D	390	straight	
	30	curve	1500
	30	straight	
	540	curve	1500
	420	curve	-1000
	300	straight	
	450	curve	2000
	240	straight	
	420	curve	1000
	270	straight	
	420	curve	-2000
	240	straight	
	450	curve	-1500
	270	straight	
	510	curve	2500
	270	straight	
	450	curve	-1500
	870	straight	
Total	6570		

Road E	540	straight	
	30	curve	3000
	30	curve	5000
	420	curve	
	150	straight	
	390	curve	-2000
	300	straight	
	450	curve	-2000
	240	straight	
	420	curve	1500
	210	straight	
	480	curve	-1000
	240	straight	
	450	curve	-1500
	270	straight	
	510	curve	2500
	300	straight	
	420	curve	1000
	720	straight	
Total	6570		