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IDENTIFICATION AND TESTING OF COUNTERMEASURES FOR SPECIFIC ALCOHOL ACCIDENT TYPES AND PROBLEMS - VOLUME II: GENERAL DRIVER ALCOHOL PROBLEM

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Government Sponsors' Addendum

The Volume I report summarizes work conducted on a study to identify and test promising countermeasures for specific kinds of alcohol related accidents. During this study, two experiments--described more fully in Volume 2--were conducted to test the effects of selected roadway countermeasures on the driving behavior of motorist-subjects who either were sober or had been drinking. In addition, literature and accident data on the magnitude and nature of alcohol involvement in drivers of heavy trucks were examined and described in a separate volume (Volume 3).

Experiment I

Experiment I was designed to determine the effect of rumble strips and raised lane delineators on measures of driver performance (e.g., speed and lane position control) for drivers who were sober or had been drinking. An instrumented vehicle driven over a closed course was used. Due to problems listed below, the reader is cautioned about accepting the contractor's conclusion that: "The overall evidence supporting the effectiveness of the rumbling treatments was positive although not strong." (Volume 2, page 191)

- Although there was one anecdotal report of a driver losing control of his vehicle after contacting the rumbling treatment, no formal data were collected or presented on such occurrences. For example, no data were presented on whether drivers "overcorrected" after contacting the rumbling treatment and drove into an opposing lane of traffic.

- Examination of Volume 2, Table 16 indicated that more rather than less lane deviations occurred in the presence of the rumbling treatments when subjects were sober. An adequate explanation of this unexpected negative finding was not presented.

Experiment II

Experiment II used a driving simulator to evaluate the effects of continuous treatments (standard and wide edgelines) and spot treatments at curves (e.g., post delineators, flashing beacons added to curve warning signs), on the driving behavior of subjects who had been drinking. In spite of positive results for edgelines (i.e., a reduction in several measures of alcohol impairment of between 30 and 46 percent for subject-motorists at the highest alcohol level), the contractor did not recommend implementation of the edgeline countermeasure nor even that additional research be conducted. Based on the results of this study, further examination of this potential countermeasure is warranted. It should be noted that the FHWA is currently conducting a research study designed to examine the effects of standard and wide edgelines on the accidents of drinking and non-drinking motorists.

The reader is cautioned about interpreting results from a number of tables presented in Volume 2. Tables 42-44 and 46, 47 (as summarized in Table 48) in Volume 2 are incomplete as only "significant two-way interactions" are presented. Other more complex effects among the six factors investigated were not presented. As an hypothetical example, if each of two types of roadway countermeasures (e.g., edgeline presence and post delineators) did not dramatically reduce the amount of weaving for drinking drivers, but their combination did, this finding would not have been presented.

Fatigue

The contractor recommended (Volume 2, page 194), that studies of accident data be conducted "... to determine if fatigue-related accident types can be identified." However, the findings from this study do not support a fatigue effect. First, only behavioral data (e.g., on vehicle position, speed) were obtained, analyzed and reported. Information on whether or not subjects were, in fact, tired was not collected, and information on heart rate, and EEG to measure the subjects state of arousal, although collected in Experiment I, were found to be too variable for use. Second, the effects of "fatigue" appeared to yield different kinds of results in the two studies. For example, in Experiment I, examination of Figures 17 and 18 shows a reduction in mean velocity (speed) for both straight and curved roadways during the second hour (segments 3 and 4). On the other hand, curve entry speeds increased during the second hour in Experiment II (Table 58). In addition, an overall measure of driving performance (i.e., pay) increased during the second hour in Experiment II. Thus, the data from this study do not suggest a fatigue-related accident type.

Heavy Truck Alcohol Problem

The Volume 3 report presents information pertaining to the magnitude and nature of the heavy truck alcohol problem. As indicated by the contractor (Volume 3, page 1), this report was largely completed by 1979. Since that time, the National Center for Statistics and Analysis has published reports* containing more recent FARS data regarding alcohol involvement in heavy truck accidents. The reader should be aware that there are data that support the contractor's findings regarding the magnitude of the problem. (The May 1984 report contains data that are nearly identical in magnitude to those reported in Volume 3, Table 13, for the High Test States.)

The reader should be cautious when making comparisons among various study findings in Section 2 of the report as it appears that the definition of "heavy truck" may have differed from study to study. For example, on page 23, the FARS definition of heavy truck--i.e., single unit vehicles above a given weight and all multi-unit trucks--was different from the one used in the Baker study and Simpson study, i.e., tractor-trailers only.

*Alcohol Involvement in Traffic Accidents: Recent Estimates from the National Center for Statistics and Analysis DOT-HS-806-269, NHTSA Technical Report, May 1982, page A3.

Fatal Accident Reporting System 1982: An Overview of U.S. Traffic Fatal Accident and Fatality Data Collected in FARS for the Year 1982. DOT-HS-806-566, May 1984, page 17 - Figure 6.

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16. Abstract

This report summarizes work conducted to investigate the feasibility of developing effective countermeasures directed at specific alcohol-related accidents or problems. In Phase I, literature and accident data were reviewed to determine the scope and magnitude of the driver-alcohol problem among vehicle drivers in general and heavy truck drivers in particular. Single vehicle accidents, head-on collisions, and to a lesser extent, rear-end collisions, were identified as alcohol collision types.

In Phase II, prospective countermeasures were identified and evaluated according to their expected effectiveness, state of development, and potential for empirical evaluation. Roadway treatments were selected for evaluation in Phase III, which consisted of two experiments. Experiment I evaluated a simulated rumbling shoulder treatment combined with a simulated raised pavement marker. An instrumented vehicle driven over a closed-course was used. The results indicated strong and consistent effects of alcohol on driving performance, including increases in lane position errors and vehicle control variability. Effects of the rumbling treatments were positive although not strong.

Experiment II used a driving simulator to evaluate continuous (standard and wide edgelines) and spot treatments for curves (herringbone patterned pavement markings, flashing beacons added to curve warning signs, chevron alignment signs, and post delineators). Alcohol effects were evident primarily on measures of tracking behavior and overall scenario performance. Edgeline presence improved tracking as well as overall performance. Wide edgelines were associated with additional, although non-significant benefits. The effects of spot treatments were relatively weak and equivocal Based upon the results, recommendations for additional research and development are presented.

The final report is published in four volumes:

Volume I - Executive Summary
Volume II - Problem Analysis and Preliminary Evaluation of Selected Roadway Countermeasures for the General Driver Alcohol Problem
Volume III - The Heavy Truck Alcohol Problem
Volume IV - Appendices

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FOREWORD

This is the final report of a study conducted by Calspan Field Services, Inc. (CFSI) for the National Highway Traffic Safety Administration under Contract DOT-HS-9-02085. Additional funding for the experiments conducted in Phase III of the study was provided by the Federal Highway Administration.

The study was initially proposed by Mr. Kenneth Perchonok, who left CFSI before the contract was awarded. The initial problem formulation phase of the study (Phase I) was directed by Dr. Kenneth W. Terhune of CFSI. The second and third phases of the study, involving the identification, evaluation and testing of countermeasures, was directed by Mr. Thomas A. Ranney.

Phase III data collection was conducted by the Human Factors Division of the Texas Transportation Institute (Experiment I) and Systems Technology, Inc. (Experiment II). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

ACKNOWLEDGMENTS

The authors wish to thank the numerous individuals whose effort was essential to the completion of this study. Thanks are expressed to the Human Factors Division of the Texas Transportation Institute for the collection of data for Experiment I, and for their hospitality and support for the long and arduous data analysis task, conducted at TTI. The efforts of Dr. Rodger Koppa and Mr. Kenneth R. Banning are especially appreciated. Thanks also go to Messrs. Mark Stuart, John Holmgreen, and Charles Raab for running the experiment.

Experiment II was conducted by Systems Technology, Inc. Thanks are expressed to Mr. R. Wade Allen for his contributions to the experimental design and data collection design and to Mr. Anthony C. Stein and his assistant Ms. Marcia Cook for running the experiment. Valuable technical support for both experiments was also provided by Dr. Alison Smiley, formerly of the Southern California Research Institute.

The successful completion of the study was made possible by the support of our sponsors. Dr. Thomas G. Ryan, formerly of NHTSA, was largely responsible for expanding the scope of the study to allow two experimental evaluations to be conducted. Messrs. Richard Schwab and Burt Stephens of FHWA were helpful in the planning and execution of the two experiments. Dr. Marvin Levy, of NHTSA, monitored the final stages of the study.

Several staff members of Calspan Field Services were especially helpful during the course of the project. Mrs. Linda O. Parada helped with the data analysis and Mrs. Betty Archer prepared the manuscript.

1. INTRODUCTION

The objectives of this study were to evaluate what is currently known about the scope and nature of the driver-alcohol problem among vehicle drivers in general and heavy truck drivers in particular, and to identify and assess prospective countermeasures for the identified problems. The study included three phases, the first of which examined extant research and data in order to identify the specific problems of alcohol-impaired drivers. The second phase involved the identification, preliminary assessment and development of test specifications for countermeasures which address the major problems identified in Phase I. Phase III involved an empirical evaluation of countermeasures selected during Phase II. The final report for this study is presented in four volumes, including an Executive Summary (Volume I), the results for the general driver-alcohol problem (Volume II), the results for the heavy truck alcohol problem (Volume III) and appendices to the general driver alcohol problem (Volume IV).

In this volume, work pertaining to the general driver-alcohol problem is reported. Section 2 presents a discussion of the nature of the problem, focusing on the way in which alcohol impairment effects contribute to accident causation. A review of accident studies is followed by a brief review of experimental literature. Convergent findings are then used to develop alcohol accident scenarios and identify targets for countermeasures.

Section 3 summarizes work conducted in Phase II of the study on the identification and preliminary evaluation of countermeasure concepts. Countermeasure identification followed the guidelines set forth in the statement of work which focused attention on the reduction of pre-crash behavioral errors related to accident causation. Approaches were selected which assume the existence of drinking drivers on the road. Through a search of literature, discussions with noted safety experts, and analysis of the identified alcohol accident scenarios, a list of prospective countermeasures was developed. An informal evaluation was then conducted to determine the expected effectiveness of each treatment, the amount of development and testing necessary before implementation, and the feasibility of testing in

Phase III. Section 3 concludes with a list of recommendations for further research and development.

Section 4 of this report summarizes all Phase III work, which consisted of two separate experimental evaluations of selected roadway treatments. Experiment I was a closed-course evaluation of two rumbling treatments, which were simulated with the servo-steering mechanism of the Driver Performance Measurement and Analysis System (DPMAS). Data collection was conducted by the Human Factors Division of the Texas Transportation Institute (TTI).

Experiment II was a simulator study of selected roadway delineation treatments conducted by Systems Technology, Inc. (STI). Two continuous treatments (standard and wide edgelines) as well as four spot treatments in the approach to curves (post delineators, chevron alignment signs, flashing beacons on curve warning signs, and a herringbone patterned pavement marking) were evaluated. The methodologies, procedures and results from both experiments are presented in Section 4.

Section 5 summarizes the results of the two experiments. Section 6 presents conclusions concerning the potential effectiveness of the various treatments tested. Section 7 presents recommendations for additional research and development. Section 8 contains references cited throughout this volume.

2. NATURE OF THE GENERAL DRIVER ALCOHOL PROBLEM

Attempts to reduce the behavioral errors associated with alcohol-impaired driving require knowledge of the nature of the errors and the circumstances in which they occur. In this section, the question of how alcohol contributes to accident causation is addressed. First, a review of existing accident research studies is presented to establish the types of accidents which consistently involve alcohol. This includes a discussion of collision types and related details of time, place and circumstances. Hypotheses are generated regarding the nature of the behavioral errors preceding the main alcohol-accident types.

Next, hypothesized errors are addressed through examination of experimental literature pertaining to the effects of alcohol on performance measures related to driving. The accident and experimental results are then combined to identify targets which include variables or combinations which have potential for reductions in alcohol accidents. Finally, using all preceding information, accident scenarios are developed and presented as a basis for countermeasure concept development which is discussed in Section 3.

2.1 Characteristics of Alcohol-Related Accidents*

Identifying the kinds of accidents associated with alcohol involvement serves two important purposes. First, it helps to clarify what it is that the countermeasure should prevent or alleviate. Second, it provides important clues as to how alcohol impairment causes accidents. In this section, the distinctive characteristics of alcohol accidents will be reviewed.

Collision type. An important variable for describing alcohol involvement in accidents is the collision type, or "manner of collision" in which the impaired driver is especially likely to be involved. To be sure, alcohol impairment may increase a driver's chances of any kind of collision, but it does appear that the representation of drinking drivers is considerably higher in some types of collisions than in others. Several studies have found, for example that alcohol involvement is greater in single-vehicle crashes than in multi-vehicle ones (Table 1). Notice that alcohol-involvement increases with the severity of the accident.

More useful are data from specifically delineated collision types, shown in Table 2. While the absolute proportions of alcohol involvement increase with crash severity, the relative proportions are highly consistent among the three studies. As in Table 1, single vehicle accidents have the most drinking drivers, with head-on (opposite-direction) crashes having the second most frequent.

An important difference distinguishes the Perchonok (1978) and Terhune (1982) data from the FARS results in Table 2. The collision types in the first two identify the role of individual driver-vehicles. In the Terhune data, for example, a "rear end strike" (i.e., the striking vehicle in a rear-end crash) is distinguished from a "rear end struck" crash (i.e, the forward, or struck, vehicle); alcohol-involved drivers are 16 times more common in the

*This section is Terhune's updated version of material originally appearing earlier (Terhune et al., 1980).

TABLE 1. - ALCOHOL INVOLVEMENT IN SINGLE-VEHICLE AND MULTIPLE-VEHICLE ACCIDENTS

Source	Accident Severity	% Drivers with Positive BAC's: Single-Vehicle Accidents	% Drivers with Positive BAC's: Multiple-Vehicle Accidents
Borkenstein, et al. (1964)	All Kinds	41% (443)	15%* (5,504)
Farris, et al. (1976)	Injured Drivers	46%** (617)	32%** (902)
Filkins, et al. (1970)	Fatal	74% (108)	63% (196)
Haddon and Bradess (1959)	Fatal	81% (117)	69% (84)
Nielson (1969)	Fatal	65% (2,521)	41% (2,602)
Waller, et al. (1969)	Fatal	69% (244)	18% (270)

( ) = Denominators for percentages, e.g., of 443 single vehicle accidents, 41% involved drivers with positive BAC's.

*Two-vehicle or pedestrian collisions

**Proportions with BAC > .03%

TABLE 2. - REPRESENTATION OF DRINKING DRIVERS IN COLLISION TYPES

Mixed Crashes[1]	% Drinking Drivers
Lane/road departure (1,484)	32%
Single-vehicle forward impact (283)	27%
Head-on & similar crashes (272)	20%
- - - - All types - - - -	16.7%
Rear-end (682)	13%
Sideswipe & similar crashes (80)	11%
Rearward (98)	9%
Left Turn (166)	8%
Right angle & similar crashes (377)	6%

Injured-Driver Crashes[2]	% Drinking Drivers
Lane/road departures (111)	59%
Single-vehicle forward impact (20)	40%
Opposite direction strike (9)	33%
Rear-end strike (41)	32%
- - - - All types - - - -	25.3%
Turn-across-path (57)	11%
Intersecting path (65)	8%
Turn-into-path (43)	7%
Opposite direction struck (21)	5%
Rear-end struck (54)	2%
Other (34)	24%

Fatal Crashes[3]	% Drinking Drivers
Single Vehicle (8,593)	73%
- - - All types - - -	58.7%
Head-on (2,858)	49%
Sideswipe (460)	47%
Rear-end (843)	44%
Rear-to-rear (16)	44%
Angle (3,302)	35%

[1] From Perchonok (1978); "culpable" drivers only; alcohol involvement from police judgment; Western New York.

[2] From Terhune (1982); alcohol involvement from blood tests; Rochester, N.Y. metropolitan area.

[3] From Fatal Accident Reporting System (FARS), 1977-78; from 9 states in which driver BAC test rate exceeded 80%. (California, Colorado, Delaware, Nevada, New Hampshire, New Jersey, Oregon, Washington, & Wisconsin)

Note: Each percentage is the proportion of all drivers in the crash type (shown in parenthesis) who had been drinking. Percentages are not addable across types. In Perchonok's data, percentages were weighted for sampling fractions.

striking vehicle than in the struck one. A similar phenomenon is shown for head-on crashes.* By not separating striking from struck vehicles, the FARS data are unable to reveal the relation of alcohol to such collisions.

Except for the outstandingly high alcohol proportions in the single-vehicle crashes, the proportions tend to change gradually between adjacent collision types. This suggests that with the exception of single vehicle accidents, a sharp demarcation of an "alcohol collison type" is necessarily artificial. For our purposes, however, it is useful to identify such types as those which have above-average representation of drinking drivers. By this criterion, the following may be considered "alcohol collision types":

(a) Single vehicle crashes (FARS, 1977-78; Perchonok, 1978; Terhune, 1982)

(b) Opposite-direction, striking vehicle - (Perchonok, 1978; Terhune, 1982)

(c) Rear-end, striking vehicle (Terhune, 1982 only).

The last has to be considered a more tentative identification, since only one study provided data on striking and struck vehicles separately.

The high alcohol involvement in some collision types suggests that alcohol impaired drivers are especially prone to an accident of that type.** Without detailed exposure data, it is not possible to say whether the high alcohol involvement is due to the impairment per se or to the conditions under which impaired drivers tend to be on the road. Part of the reason for their overrepresentation in single vehicle crashes, for example, may be due to greater exposure of drinking drivers to nighttime, low traffic conditions. Whatever the explanation, above average representation of drinking drivers seems a reasonable criterion for identifying an alcohol collision type.

*The Perchonok data were presented only for "culpable" drivers, hence they are likely to represent only the striking vehicle in such crashes.

**More precisely, proneness is suggested for any collision in which the proportion of drinking drivers exceeds the proportion on the road.

Alcohol collision types may also be evaluated by the proportion of all drinking-driver crashes they represent, a criterion we call prevalence. Table 3 shows the prevalence of the various crash types. The single driver/lane-road departure crash type is far and away the most prevalent. Thus, high prevalence and high overrepresentation, especially in fatal crashes, indicate this to be a highly important alcohol accident type. Considerably less prevalent are the rear-end striking/culpable crashes, though they are second in the listings from the Perchonok and Terhune studies. The lesser prevalence of rear-end collisions in the fatal crashes is probably due to their lower severity. Head-on crashes, which tend to be very severe, are fairly prominent among the fatal crashes, but are less so among the others. The single-vehicle forward impact type (stationary target ahead) is the next most prevalent type in the Perchonok and Terhune data, and it would be included among the single-vehicle FARS data. Beyond these types, the relative frequencies are quite low.

In conclusion, single-vehicle crashes, head-on striking crashes, and rear-end striking crashes are three collision types toward which drinking drivers seem most disposed. Of these, the single-vehicle types are preeminent in frequency.

Speeding in accidents. Zylman (1975) asserted that the majority of drivers arrested for impaired driving had not been speeding, but merely attempting slowly to negotiate their trip. He contrasted these with heavy drinkers in fatal crashes, who he said, have "frequently" been driving at high speed. This suggests two different drinking-driver reactions, but leaves open the question as to whether there is a general relationship between drinking and propensity to speed.

Indications within major studies have shed light on the matter. Studies do indeed seem to indicate a connection between alcohol and speeding, among those who get into accidents. Data on fatal accidents (Filkins, et al., 1970), representative North Carolina accidents (Fingerman, 1977),

TABLE 3. - PREVALENCE OF COLLISION TYPES IN DRINKING-DRIVER CRASHES

Mixed Crashes[1]	%
Lane/road departure	42
Rear-end	14
Head-on & similar crashes	7
Stationary target ahead	7
Right angle & similar crashes	5
Left-turn	3
Sideswipe & similar crashes	2
Rearward	2
Others	20
Total	100%*

Injured-Driver Crashes[2]	%
Lane/road departure	57
Rear-end strike	11
Single-vehicle forward impact	7
Turn-across-path	6
Intersecting path	4
Turn-into-path	3
Opposite direction strike	3
Opposite direction struck	1
Rear-end struck	1
Other	7
Total	100%*

Fatal Crashes[3]	%
Single Vehicle	65
Head-on	15
Angle	13
Rear-end	4
Sideswipe	2
Rearward	0
Other	2
Total	100%*

[1] Perchonok, 1978 (N = 2863)

[2] Terhune, 1982 (N = 497)

[3] FARS, 1977-78 (N = 9612)

*Rounded

Western New York accidents (Perchonok, 1978) and truck accidents (Ernst and Ernst, 1968) all exhibit a positive association between drinking and estimated vehicle speed. For example, the Filkins, et al. (1970) data indicate a median speed of 33 MPH for the non-drinkers and 46 MPH for drinking drivers*; eight per cent of the drinking drivers were estimated as exceeding 80 MPH, while none of the non-drinking drivers was judged to be driving that fast. There are problems with such data, however, in that: (a) they reflect only on drivers in accidents, not all drivers; (b) vehicle speeds are retrospective estimates only; and (c) the distinction between travel speed and impact speed is not made.

Time of day and lighting. Several studies indicate that driver alcohol involvement is most pronounced in crashes taking place at night (Jones and Joscelyn, 1978; Perchonok, 1978; Terhune, 1982). It is important to consider whether that is simply because there are proportionately more drinking drivers on the road at night than during the day, or whether drinking drivers actually have more difficulty under conditions of darkness. The Grand Rapids and other studies indicate that there are in fact more alcohol-involved drivers on the road during nighttime hours (e.g., Table 4). Thus, the preponderance of drinking drivers in nighttime accidents may partially reflect the proportion of drinking drivers on the road at that time. That is not the whole story, however. With data on police-reported alcohol involvement, Perchonok (1978) found that nighttime accidents of drinking drivers were more often in unlighted areas than were the night accidents of apparently sober drivers. This was confirmed in Terhune's (1982) study. It was found that 38 per cent of the alcohol-involved night accidents occurred in unlighted areas, compared with only 23 per cent for the sober drivers. These results suggest that alcohol impairment increases risks when driving in darkness. The alternate explanation would have to be that not only are alcohol-impaired drivers overrepresented on the road at night, they are also overexposed to unlighted streets.

*Our computations from their data.

TABLE 4. - DRIVER ALCOHOL INVOLVEMENT: RUSH HOURS VS. EARLY MORNING
(Grand Rapids Data from Zylman, 1968)

A. 3:00 PM to 6:00 PM Period

	Blood Alcohol Concentration						
	0	.01-.04%	.05-.07%	.08-.11%	.11%+	Total	N
Accident Group	86.9%	6.6%	1.4%	1.5%	3.6%	100.0%	1677
Non-Accident Group	92.0%	6.3%	0.8%	0.7%	0.2%	100.0%	2139

B. Midnight to 3:00 AM Period

	Blood Alcohol Concentration						
	0	.01-.04%	.05-.07%	.08-.10%	.11%+	Total	N
Accident Group	43.1%	16.3%	7.8%	10.9%	21.9%	100.0%	320
Non-Accident Group	63.9%	18.9%	10.3%	4.5%	2.4%	100.0%	465

Day of week. Accidents tend to involve drinking more on weekends than on weekdays, though the effect is not as pronounced as the time-of-day effect (Jones and Joscelyn, 1978). The weekend effect seems a reflection of general drinking patterns.

Geographical location of accident. Two studies that have examined geographical location of accidents with respect to alcohol involvement were by Perchonok (1978) and Terhune (1982). The proportion of police-reported drinking drivers in Perchonok's study was greatest in rural areas (20.5%) and smallest in urban areas (12.9%). In Terhune's metropolitan area study, no differences were found between urban and suburban locations.

Road characteristics. Of three studies that have examined aspects of the road on which accidents occurred, the following were the main findings:

- Curves -- While a majority of accidents take place on straight road sections, alcohol-involved drivers are consistently found to be overrepresented in curve accidents. Although Filkins, et al. (1970) found drinking drivers only 23 per cent more frequent in curve fatal accidents, the Perchonok (1978) and Terhune (1982) studies found alcohol-involvement at least twice as frequent in curve accidents as in noncurve ones.

- Intersections -- While the majority of accidents are found to occur at locations other than intersections, the Perchonok and Terhune studies found alcohol involved crashes especially likely to be away from intersections. This fact reflects the collision type data shown previously, whereby drinking drivers were predominantly in road departure crashes and infrequently in angle collisions.

- Road type -- Perchonok (1978) found some evidence for alcohol accidents to be more common on two-lane roads in his Western New York study, while Terhune's metropolitan area study found no relation between alcohol involvement and accident road type.

Alcohol accident types. Considering the several factors that have been found associated with alcohol involvement in crashes, it is potentially useful to identify the factors or their combinations that are most associated with alcohol crashes. One study (Terhune, 1982) examined "alcohol accident types", which were operationally defined as the sets of accident circumstances in which alcohol involvement was the highest. It was found that the following three crash circumstances accounted for 75 per cent of all alcohol-involved drivers:

- Single vehicle; midnight - 6 AM; on curve -- 95 percent alcohol involvement
- Single vehicle, midnight - 6 AM; on straight section -- 83 per cent alcohol involvement
- Multiple vehicle; midnight - 6 AM -- 52 per cent alcohol involvement

Although these data come from only one metropolitan area, they show that certain crash circumstances may indicate very high probability of an alcohol-impaired driver. While that probability will result from high exposure and/or high crash proneness, the crash circumstances suggest important targets for alcohol countermeasures.

2.2 Underlying Behavioral Impairments.

The level of detail typically available from accident data precludes identification of specific behavioral errors related to accident causation. The various characteristics of alcohol-related accidents are, however, suggestive of impairment effects. In this section, the results of accident studies, plus one observational study, which pertain to impairment effects are reviewed to identify hypothesized "behavioral errors." In the following section, a brief review of experimental literature is presented.

2.2.1 Lowered Arousal

Accident data analyses suggest that as BAC level increases, the driver's general level of alertness decreases. At high BACs, accident patterns suggest gross lapses of attention and failure to negotiate even relatively undemanding driving situations. The clues that indicate lowered arousal to be a major alcohol impairment effect in accidents are as follows:

- There is high drinking-driver involvement in accidents of low external demand situations (single-vehicle accidents, rural roads, etc.). In the FARS and Detroit area data, road-departure accidents increased with higher BAC.

- BAC levels are higher in single-vehicle fatal accidents; 60% of drivers killed had BACs of .10% or higher (Filkins, et al., 1970, Haddon and Bradess, 1959; Jones and Joscelyn, 1978; data compiled from Neilson, 1969; Perrine, et al., 1971; Waller, et al., 1969).

- Analysis of data from CFSI's Single Vehicle Accident Study (Perchonok, et al., 1978) revealed that alcohol-involved drivers were significantly less likely to have attempted a corrective response (e.g., braking or steering) prior to road departure, which is suggestive of passive road departures resulting from lowered arousal.

2.2.2 Impairment of Time-Sharing (Divided Attention).

Because of the difficulty of identifying impaired time-sharing from accident data, this impairment effect must be judged as more tentative, or less clear, than lowered arousal. Nevertheless, there is evidence suggesting that this may be an alcohol impairment significant to accident causation, and there is reason to believe it could operate at low BAC levels as well as high ones. Specifically, the findings are as follows:

- In the Grand Rapids study (Borkenstein, et al., 1964), low as well as high-BAC drivers were overrepresented among accident drivers in the high-demand, rush hour period; in the lower-demand, early-morning accidents, only high-BAC drivers were overrepresented among accident drivers.

- Within the Detroit area, right angle accidents were the most prominent type for low-BAC drivers, whereas the primary accident type shifts to road-departure accidents for high-BAC drivers (Filkins, et al., 1970).

- In a recent accident study by Brewer and Sandow (1980), drinking drivers were found significantly more than sober drivers to have been distracted by an activity peripheral to the driving task moments before their crashes.

While loss of time-sharing ability would seem especially likely to create problems in high-demand, dense traffic situations, the Brewer and Sandow study found driver distraction prominent in drinking-driver, single-vehicle crashes. It may be relevant to all accident types.

2.2.3 Recklessness and Speeding.

This possible alcohol impairment effect has been difficult to establish, because of the problem of estimating travel speed (as opposed to impact speed) in accidents. Nevertheless, there are sufficient data to infer that recklessness and/or speeding is related in some way to alcohol involvement.

- Alcohol-involved accident drivers were estimated to have been traveling at higher speeds than sober accident drivers in some studies (Ernst and Ernst, 1968; Filkins, et al., 1970; Fingerman 1977; Perchonok, 1978).

- Drinking drivers in mixed-severity accidents were more often cited for speeding or reckless driving (8%) than were nondrinkers (3%) (Perchonok, 1978).

- Drinking driver accidents were more frequently attributed to active loss of control (15%) than were accidents of nondrinkers (7%) (Perchonok, 1978).

- Although one study (Damkot, et al., 1977) found no relation between BAC and on-the-road travel speed of drinking drivers, this is explainable by results of another study (Harris, et al., 1979): excessively high <u>and</u> low speeds were found to be significant indicators of driver impairment.

- In an observational study (Harris, 1980), erratic acceleration and excessive speed were among the observable cues associated with alcohol impairment.

Terhune (1982) suggested that the results of the various studies may be explained by a combination of the following four hypothesized principles:

(1) On the <u>average</u>, alcohol impaired drivers are not more inclined to speed than sober ones;

(2) <u>Some</u> drivers are inclined to speed under the influence of alcohol, while others drive too slowly;

(3) When an alcohol-impaired driver speeds, he is less able to handle his vehicle safely than a sober driver who speeds;

(4) When a crash is impending, an impaired driver is less successful in slowing his vehicle.

2.2.4 Lane Maintenance Problems

The prominence of road departures among the accidents of alcohol-impaired drivers, especially in situations of low external demand, as well as the increased likelihood of head-on collisons, suggest that maintenance of vehicle position within the travel lane is difficult for alcohol-impaired drivers. This conclusion is supported by the results of Harris, et al.(1979), who identified observable cues associated with alcohol impairment. Using data from that report, Table 5 was constructed to compare the prevalence of the various behaviors exhibited by intoxicated drivers. Note that problems of lane maintenance account for over forty percent of the observed DWI events.

2.2.5 Summary of Underlying Impairment Effects

Based upon the accident and observational studies reviewed, four basic impairment effects have been identified. Of these, two (lower arousal and impaired time-sharing) are psychological constructs relating to information processing, attention, and alertness. The other two (speeding and lane maintenance problems) refer to problems of vehicle control and are not unrelated to the first two.

Lowered arousal and decreased alertness are supported by the accident data findings that impaired drivers often fail to attempt an appropriate corrective response (braking or steering) prior to collision on road departure. The time-sharing decrement pertains to the acquisition and processing of information. Although strongly supported by laboratory studies (see Section 2.3), accident data are generally not sufficient for directly identifying the occurrence of this impairment effect.

TABLE 5. - PREVALENCE OF DWI EVENTS
(Data from Harris, et al., 1979)

Lateral Vehicle Control Problems (Tracking, Lane Maintenance)	Percentage of DWI Events
Weaving	11
Drifting	8
Straddling Lane Marker	6
Tires on Lane Marker	7
Swerving	4
Turn with Wide Radius	3
Almost Striking Another Vehicle or Object	2.5*
TOTAL	41.5 %
Longitudinal Control Problems	
Fast Speed	6
Slow Speed	1*
Rapid Acceleration or Deceleration	6
Stop Without Cause	1
Following too Closely	3
Almost Striking Another Vehicle or Object	3
TOTAL	2.5*
	22.5 %
Time-Sharing/Information Processing Rate, Other Confusions	
Driving on Other Than Designated Roadway	4
Slow Response to Traffic Signals	2
Signalling Inconsistent with Driving Actions	4
Failing to Respond to Traffic Signals	5
Stopping Inappropriately Other Than in Lane	2
Turning Abruptly or Illegally	2
Driving into Opposing or Crossing Traffic	2
Slow Speed	1*
TOTAL	22 %

*Percentages associated with behaviors applicable to more than one category were split among the relevant categories.

Unsafe speed is a commonly observed alcohol impairment effect, having been found in both accident and observational studies. Whether high speeds result from misinterpretation of information (impaired information processing) or disinhibition and intentional risk-taking cannot be determined from accident data. Experimental studies (Section 2.3) have addressed this question.

Like speeding, problems of lateral vehicle control are commonly observed alcohol-impairment effects. The large number of single vehicle road departure accidents where external demands are minimal, and the over-involvement of alcohol impaired drivers in head-on collisions support the importance of this effect. Lane maintenance problems could be related to time-sharing decrements in that tracking is one of the main components which must be time-shared with all other components.

2.3 Experimental Studies of Alcohol Effects on Driving

Much experimental research has been conducted on the effects of alcohol on human performance and skills related to driving (cf. Ryder, et al., 1981; Moskowitz and Austin, 1979). No attempt will be made to provide an exhaustive review of this literature. Rather, relying primarily on the existing reviews referenced above, a summary of the effects of alcohol on the behaviors suggested in the previous section as being related to accident causation is presented. The review will focus primarily on studies which involve real or simulated vehicle driving. A brief discussion of the various research methodologies, including their strengths and weaknesses precedes this review.

2.3.1 Research Methods for Studying Alcohol Impairment Effects on Driving

The major research methods for studying alcohol impairment effects on driving are closed-course experiments and driving simulation. Closed-course experiments involve use of vehicles equipped with performance monitoring equipment and dual controls on closed roadway systems. Driving simulators typically utilize fully or partially instrumented cabs and filmed or computer-generated projections of roadway features and other traffic. Controlled on-road studies generally are not feasible for studying alcohol impairment effects due to potential legal and safety problems.

According to Ryder, et al.(1981), studies which involve actual driving are directly generalizable to driving because of the comparable task complexity and response. This point was also made by Huntley (1974) who suggested that the use of real cars provides the potential for both high face validity and operational validity. Because the driving takes place in a closed environment, the range of traffic conditions which can be simulated is limited. For example, interaction with other vehicles (e.g., oncoming traffic) is generally not possible in an experimental situation where subjects are alcohol-dosed. Regarding the use of closed-course experimentation for the study of alcohol effects, Huntley (1974) concluded that relatively unstructured task situations may be more susceptible to alcohol effects than the highly structured "gymkhana" course studies.

The use of driving simulators allows greater flexibility in the specification of driving situations, but at the loss of generalizability to actual driving. According to Allen, et al.(1979), there are at least 20 research driving simulators throughout the U.S. and Europe. Simulators differ primarily in terms of the type of visual display and the availability of motion. According to Moskowitz and Austin (1979), no simulator adequately samples the totality of behavioral driving demands, and because simulators differ greatly, it is unlikely that they make the same behavioral demands of subjects. This explanation is given for the finding that much of the research using driving simulators has been contradictory (Moskowitz and Austin, 1979). In a discussion of validity of driving simulator studies, Moskowitz (1974) does argue, however, that although driving simulator research may not be consistent in terms of response variables, analysis at the level of "psychological function" (e.g., rate of information processing or time sharing) appears to indicate reliable agreement among different simulator studies. The validity of driving simulators has also been addressed by others (Edwards, et al., 1969; Allen, et al., 1978).

A concern of relevance for all experimental studies of driving behavior is the fact that subjects are aware that their performance is being monitored (Ryder, et al., 1981). This point, together with the fact that subjects are generally aware that they face no real danger, has been used to suggest decision-making requirements in experimental situations do not adequately reflect the actual risks and contingencies of real-world driving. Because of these artificialities, it is likely that the observed behavior is more indicative of maximal task performance rather than usual performance (Ryder, et al., 1981).

2.3.2 Arousal/Alertness

The concept of attention is generally divided into two components, one referring to the ability to maintain alertness or adequate concentration, and a second referring to the selection of information from a number of competing sources. The former aspect of attention is referred to as the intensive aspect and is related to the level of arousal. Ryder, et al. (1981) reviewed several categories of experimental research which pertain to intensive attention and vigilance. Studies using the electroencephalogram (EEG) generally show decreases in the frequency and increases in the amplitude of cortical activity with moderate and large doses of alcohol, which are interpreted as depressant effects. However, interpretation of these results is difficult due to individual differences in EEG patterns and the generally low correlations of EEG with behavioral measures.

Heart rate and galvanic skin response (GSR) have also been used as measures of arousal. Ryder, et al. (1981) refer to a review conducted by Wallgren and Barry (1970) which reports slight, short-lived increases in heart rate with moderate levels of alcohol. The effects of alcohol on GSR have not been consistent.

Moskowitz and Austin (1979) reviewed the results of several vigilance experiments, where subjects were required to monitor low quantities of information over long periods of time. They report that for individuals who are neither fatigued nor sleep deprived, the effect of alcohol is slight for low to moderate BACs.

Barry (1974) reviewed experimental literature pertaining to the motivational and cognitive effects of alcohol. He cited two reviews of laboratory studies which used alcohol-dosed animals, and reports that the sedative or generalized depressant effects of alcohol are more prominent than the stimulant effects. Based upon his review, Barry (1974) concluded that the increased risk of traffic accidents under the influence of alcohol can be attributed either to: (1) inattention or sleep; or (2) risk-taking or disorganization. Contributing to the sedative effect of alcohol is the observation the alcohol reduces fear and thus enables the driver to relax, become inattentive or fall asleep. It is suggested that there may be large individual differences in this response to alcohol.

From these reviews it is apparent that laboratory studies using animals more readily demonstrate the depressant effects of alcohol than studies using humans. This may be related to the fact that the human subjects are aware that their behavior is being monitored in the experimental situation, and thus attempt to compensate for the depressant effects of alcohol. Actual driving situations, particularly where external demands are low, may be ideal situations for the sedative effects of alcohol to decrease a driver's alertness.

2.3.3 Time-Sharing

The effect of alcohol on the capability to time-share from competing information sources is the research with perhaps the most consistent results. This topic relates to several aspects of information-processing and allocation of attention and has been examined in a number of research settings. In a review of laboratory studies which used measures relating to driving, Moskowitz (1973) concluded that when alcohol-dosed subjects are required to perform vision, tracking, or attention tasks alone the impairment effects are generally not apparent at low or moderate BACs. However, when the same tasks are combined with a more complex requirement for joint performance, decrements are observed at low BACs (e.g., 0.02%).

The initial studies which established the time-sharing effect utilized a divided attention paradigm, where a dichotic listening task was used to compare alcohol effects on divided attention versus vigilance (Moskowitz and DePry, 1968). The same result has been obtained in experiments where the time-sharing is between tasks more closely resembling the components of driving. Allen, et al. (1975) used a time sharing paradigm in a simulator where a continuous steering task was performed simultaneously with a discrete detection and recognition task. It was found that the demands of detection disrupted steering performance, while steering task demands did not impair discrete task performance.

In a review of the results of selected driving simulator studies, Moskowitz (1974) concluded:

> "It is apparently the brain's capacity of handling two tasks simultaneously that is most susceptible to alcohol impairment. Which performance task or tasks will exhibit the deficit . . . is a matter of individual emphasis by the subject." (p. 299)

According to Johnston (1982), results from the experimental literature are consistent enough to establish two "principles" concerning alcohol impairment:

(1) Information acquisition and processing is both slower and less efficient under alcohol, and

(2) The ability to time-share in divided attention tasks is significantly impaired by alcohol.

He concludes that alcohol-impairment effects are more often associated with impaired information-processing than sensory responsiveness or motor ability.

2.3.4 Speeding/Recklessness

The results of accident studies (Section 2.1) which associate high speed with alcohol involvement, together with the well-established disinhibitory effect of alcohol (Barry, 1974) have led to hypotheses concerning deliberate risk-taking and recklessness as major on-road impairment effects of alcohol. A review of relevant laboratory studies is presented by Barry (1974). Citing the earlier review conducted by Wallgren and Barry (1970), Barry identifies several studies which indicated that medium doses of alcohol increased people's willingness to accept risks. He notes, however, that the effect is "small and not entirely consistent." Subsequent research also shows a small effect.

Barry (1974) theorizes about the motivational and cognitive aspects of increased risk taking, citing the motivational components of decreased fear and increased assertiveness, along with the cognitive components of impaired self-criticism and dissociation from sober habits. According to his analysis the combination of these behaviors gives rise to increased risk-taking or disorganiztion, typical on-road consequences of which include speeding or risky maneuvers in routine driving.

Of all the aspects of alcohol impairment, risk-taking may well be the most difficult to study in the laboratory. As pointed out by Browning and Wilde (1975) the very essence of the laboratory situation is to remove the risk of accident or injury, and as such the laboratory setting can be expected to be "impotent" in detecting such effects. Concern over the artificiality of the experimental situation is also expressed by Johnston (1982), who concludes that the issue of risk-taking versus impaired decision-making is as yet unresolved.

Ryder, et al. (1981) reviewed several studies relating to impairment effects on decision-making and judgment of hazard. Two studies are cited in support of the hypothesis that under the influence of alcohol, subjects were more likely to choose a riskier alternative in hypothetical situations. Also cited are studies which indicate that under the influence of alcohol, people feel that their performance is normal or better than normal, even though objective measures show decrements. Of relevance is the classic study by Cohen, et al. (1964) where subjects under low doses of alcohol (0.04%) made attempts to drive a bus through a gap which was too narrow.

Most recently, an experimental study by Allen, et al. (1978) addressed the question of alcohol-impaired decision making. In both a laboratory simulation and a closed-course study, alcohol was found to increase risk-taking behavior. The analysis revealed that the effect was due to perceptual and psychomotor decrements, rather than increased acceptance of risk. Although a performance decrement was observed at BACs of 0.10%, it was not until 0.15% that subjects became aware of the increased risk and exhibited compensatory behavior.

2.3.5 Lane Maintenance/Tracking Impairment

According to Moskowitz and Austin (1979) the results of laboratory studies concerning the effects of alcohol on tracking behavior are fairly consistent. They present three general conclusions following their review:

(1) When performed alone, there is little evidence that alcohol impairs compensatory tracking tasks.

(2) Alcohol consistently degrades pursuit tracking which requires monitoring two or more sources of information.

(3) When any type of tracking task is performed concurrently with another activity requiring time-sharing, a decrement can be expected.

As with other impairment effects, the importance of time-sharing is evident in the interpretation of alcohol-associated tracking decrements.

Studies of on-road and simulated driving have shown alcohol-related tracking decrements using deviations from the travel lane or road position errors as the dependent measure. Ryder, et al. (1981) cite six studies which support the general phenomenon of increased road position errors with alcohol, and one contradictory study. The latter study (Mortimer and Sturgis, 1979) found no significant change in lateral position errors at a moderate BAC (0.085%) using both day and nighttime driving.

2.4 Alcohol Countermeasure Targets

In developing countermeasures to reduce alcohol impairment effects, it generally is not enough to know alcohol collision types and their inferred underlying behavioral impairments. Rather, it is valuable and sometimes essential to know driver groups, locations, times, and vehicle types for which impairment effects are manifested. Thus, it is important to identify alcohol countermeasure targets (ACTs). A formal definition of this concept is as follows:

> Alcohol Countermeasure Target (ACT) -- A category of location, time, vehicles, drivers, or combination thereof, in which the drinking-driver problem is especially prominent, and which therefore has potential for making significant reductions in drinking-driver accidents.

In order to determine which categories of people, places, etc. are potential ACTs, three evaluation criteria are relevant:

(1) Prevalence -- The proportion of drinking drivers in accidents involving the category, e.g., the proportion of male drivers in drinking-driving crashes, the proportion of drinking-driving crashes in rural locations. This criterion is useful to show the portion of the drinking-driver problem that will be reached by a countermeasure aimed at the target category.

(2) Proneness -- The extent to which the crash risk for a drinking driver is greater than for a sober driver, for an ACT category. This is a most important criterion, because it identifies the conditions which are especially hazardous to the impaired driver. Unfortunately, the exposure data needed to determine proneness are mostly unavailable.

(3) Overrepresentation -- The degree to which the proportion of alcohol-involved accidents within a category exceeds that expected by chance. One fairly useful form of overrepresentation compares the proportions of drinking drivers and sober drivers in crashes within an ACT category.

For example, if 60 per cent of drinking-driver crashes and 30 per cent of sober driver crashes occurred at night, nighttime would be overrepresented in drinking-driver crashes by a ratio of 2 to 1. A problem with overrepresentation is its ambiguity of meaning. In our example, drinking drivers may be more prominent in night crashes because they have more difficulty (proneness) with nighttime conditions, or because there are more drinking drivers at night (overexposure).

Various other forms of overrepresentation may be and have been used. For example, the proportion of males in drinking-driver accidents may be compared to the proportion of all drivers on the road who are male, or to the proportion of registered drivers who are male. These comparisons introduce additional difficulties in interpretation because they may result from such phenomena as males being more inclined to drink than females, or males tending to drive more than females.

While overrepresentation has its problems of interpretation, it can be useful for identifying categories in which there seems to be a pronounced drinking-driver problem.

Table 6 summarizes data that were found on ACT categories for the three criteria. As can be seen, proneness data are lacking in all except the dimensions of driver age and sex. The boxed numbers indicate the ACT categories of substantial overrepresentation. For example, up to 6.1 times more drivers with previous DWI convictions have been found in drinking-driver crashes than in sober ones. Similarly, drinking drivers were definitely overrepresented in nighttime accidents and crashes on curves. Further research using currently available data would enable more precise details to be established and to unconfound possible interrelationships among the variables.

TABLE 6. - POTENTIAL ALCOHOL COUNTERMEASURES TARGETS

Target Categories	Target Criteria		
Human	Prevalence*	Over-Under Representation**	Proneness***
Men	75-90%	1.2 - 1.3	Lower
Women	10-25%	0.4 - 0.6	Higher
Age 20 & under	18-25%	0.7 - 1.5	Highest
21-35	41-44%	1.1	Lower
36-65	31-39%	0.9 - 1.2	Lower
Over 65	0-2%	0 - 0.3	Higher (at BAC $\geq$ .10%)
Previous DWI	12-15%	$\boxed{4.4 - 6.1}$ +	?
No previous DWI	85-88%	0.9	?
Vehicle			
Autos	88-94%	0.9 - 1.0	?
Light Trucks	6-13%	1.2 - 1.5	?
Heavy Trucks	0-1%	0 - 0.1	?
Environment			
Night	76-82%	$\boxed{2.1 - 2.9}$	?
Day	18-24%	0.3	?
Curve	21-23%	$\boxed{2.0 - 2.7}$	?
Straight (tangent)	77-79%	0.9	?

*Prevalence is expressed as a proportion of all alcohol-involved drivers in crashes. Data are from Perchonok (1978), FARS (Terhune, et al., 1980) and Terhune (1982).

**Over/under representation is (% of all drinking drivers who are in category) ÷ (% of all sober drivers who are in category). Data sources as for prevalence.

***Proneness is based on relative risk analysis, reported by Jones and Joscelyn (1978).

+Boxed numbers indicate categories of substantial overrepresentation.

2.5 Accident Scenarios for Countermeasure Development

The convergence of results from accident and experimental studies has led to two basic scenarios of accident causation for alcohol-impaired drivers. Although all aspects of the scenarios are not strongly supported by existing data, they do reflect the characteristics which have been consistently observed in the studies reviewed.

2.5.1 Scenario 1 - Passive Road Departure or Collision

In rural, nighttime driving situations, or in monotonous freeway driving, where task demands are relatively minimal, the depressant effect of alcohol is likely to predominate, leading to lowered arousal, lapses of attention, and even sleep. The effects on driving performance are likely to include progressive deterioration of lane maintenance, leading to weaving or drifting onto the shoulder or into the oncoming traffic lane. When alcohol impairment is more severe, the result is characterized by a "passive" loss of vehicle control, leading to road departure at relatively shallow departure angles, and failure of the driver to attempt a corrective response in sufficient time to avoid an accident. If a hazard (e.g., parked vehicle) happens to be in the vehicle's path, a collision, often characterized by failure to brake, may result. In this situation, the lowered arousal leads to a reduced rate of information processing which in turn leads to a failure to detect the hazard.

2.5.2 Scenario 2 - Active Road Departure or Collision

In more demanding situations, or perhaps at lower BAC levels, where drivers are better able to maintain their general level of alertness, the unexpected appearance of a hazardous situation (e.g., sharp curve or oncoming vehicle) may induce an inappropriate response due to failure to correctly evaluate the demands of the situation. The sudden increase in task demands may overwhelm the driver, particularly if traveling at a high rate of speed. The resulting accident may involve a more "active" loss of control where the driver is attempting, unsuccessfully, to keep the vehicle on the road.

3. COUNTERMEASURE APPROACHES

One major objective of the project was to identify countermeasures for the general driver alcohol problem which reduce the consequences of alcohol-impaired driving. In contrast to deterrent approaches which attempt to remove impaired drivers from the road, this approach assumes that there will always be some drinking drivers on the road and that countermeasures which reduce the likelihood or severity of an accident can be useful complements to deterrent approaches. The essence of the approach is to identify the specific behavioral "errors" that contribute to the causation of alcohol-related accidents, and to develop and implement countermeasures which reduce these errors. In this regard, the approach emphasizes accident prevention rather than severity reduction. The discussion of general approaches and specific countermeasures is preceded by a brief review of literature pertaining to countermeasure theory.

3.1 Background

Theoretical approaches to highway safety countermeasures have traditionally been been derived from epidemiologic methods (c.f. Haddon, et al., 1964). Haddon and Baker (1980), for example, identify ten strategies applicable for prevention or minimization of the consequences of all kinds of injuries, including recreational, work-related, as well as highway safety-related injuries. Several theoretical considerations are advocated by these authors including preference of passive approaches which require no participation by the user rather than active (i.e., behavioral modification) approaches. A mixed strategy is recommended, combining countermeasure approaches which address all (pre-crash, crash, and post-crash) phases of accidents. These authors also argue that the choice of countermeasure should not be determined by the relative importance of the causal or contributing factors, or by their earliness in the accident sequence of events. This recommendation is directed primarily at what the authors perceive as undue emphasis on trying to correct the human error, which is generally considered to be the most important causal factor in highway accidents.

While the immediate causal sequence of events may not always be the most important point of intervention for highway safety countermeasures, understanding or at least recognizing the multitude of variables involved in the event (i.e., accident) and their interactions is important for developing effective countermeasures, according to Hagen (1970). However, because different classes of accidents may have different associated variables, effectiveness can be expected to differ among accident classes. Therefore, major injury control programs undoubtedly all require a variety of countermeasure approaches, a point emphasized by Haddon and Baker (1980). Existing countermeasure approaches are separated by Hagen (1970) into (1) environmental modifications, which include changes to the vehicle or roadway, and (2) behavioral modifications, which include education, coercion, and legal sanctions. Unlike Haddon and associates, Hagen makes no claim that one approach is necessarily more effective than another.

The development of accident-specific alcohol countermeasures is supported by Johnston (1980, 1981, 1982), based on the assumption that there will always be some drinking drivers on the road. According to this logic, it therefore makes sense to attempt to identify the locations and the types of accidents to which the impaired drivers seem especially prone. Through further analysis of the causal factors involved in each class of accidents, accident-specific countermeasures can be developed. It is this approach which is followed in this study.

3.2 General Approaches to Alcohol Countermeasures

The specifications of the Statement of Work serve to restrict the focus of the study to pre-crash (accident preventive) countermeasures intended to reduce the "behavior errors" associated with alcohol-related accidents. The previous sections have reviewed the available literature pertaining to alcohol-related accidents and the underlying impairment effects. Based upon these reviews, a number of general approaches to alcohol countermeasures have been identified. These are discussed briefly.

(1) Arouse impaired driver - One major behavioral impairment associated with single vehicle lane/road departure accidents appears to be lowered arousal. In situations with low external demands (e.g., rural, nighttime driving), lowered arousal leads to lapses of attention, progressive deterioration of tracking performance, and eventual loss of vehicle control. One possible approach to intervention involves arousing an underaroused driver. Implementation could be accomplished through in-vehicle devices which monitor driving performance and, upon detection of an appropriate decrement, transmit an arousing signal to the driver. Alternatively, this approach could involve the use of roadway alerting devices such as rumble strips on the shoulder of the road or raised delineators which arouse the driver through vehicle vibration when the vehicle deviates from the lane or roadway. Arousing stimulation, with no specific information content, is hypothesized to be most appropriate for drivers with high BACs who may be unable to interpret specific information such as performance feedback.

(2) Alert impaired driver to hazards - At lower or intermediate BACs, or when the impaired driver is able to maintain general alertness, a major impairment effect is a reduced rate of information-processing. Drivers in this condition may be unable to respond appropriately to sudden increases in task demands. Alerting impaired drivers to the existence of a specific hazard is proposed as a possible means of counteracting this type of problem. In-vehicle warning devices along with various roadway alerting devices such as rumble strips on the approach to an unexpected hazard (e.g., with restricted sight distance) and active (flashing) displays are specific examples of countermeasures intended to alert an impaired driver. This strategy differs from the first in that a more specific message is provided to the driver, concerning on-road hazards.

(3) Enhanced information presentation - Impaired information-processing makes it difficult for the alcohol-impaired driver to negotiate road sections with relatively routine external demands, depending upon the level of impairment. To address this problem, approaches which enhance existing infor-

mation, either through redundant sign messages, improved delineation treatments, or in-vehicle devices to provide performance feedback (e.g., lane position and speed information) are proposed. This approach differs from the previous one in that no assumptions are made about the hazardousness of the environment.

(4) Provide additional skills - One possible approach to reducing the effects of alcohol impairment in driving is to provide drivers with a set of specific skills which can be used in the avoidance of alcohol-related or similar crashes. The objective is to provide skills which either are robust to the effects of alcohol impairment or which include strategies for compensating for impairment effects (e.g., enable driver to identify cues of impaired driving such as lapses of attention).

3.3 Specific Candidate Countermeasures

Based upon a search of existing highway safety literature, a solicitation of ideas from selected alcohol-highway safety experts, and an analysis of alcohol accident types to identify potential new countermeasures, a number of countermeasures were identified. Categorized by locus of application, the identified candidates are discussed in the following sections.

3.3.1 Vehicle Modifications

Included in this category are all devices which either monitor driver performance to detect impairment or monitor the environment to detect hazards or critical decision-making situations. Vehicular modifications designed to increase the conspicuity or detectability by drivers of other vehicles are also included.

Performance monitoring devices - The basic concept of performance monitoring and feedback was implemented in a prototype system which was marketed for use in heavy trucks (Moore, et al., 1975). The system (called the Owl system) monitored the steering wheel reversal rate and compared it to a pre-established criterion. If the observed rate was found to deviate significantly from the criterion, a warning tone was sounded to alert (arouse) the driver. Although marketed as a device to counteract drowsiness, the apparent similarity of alcohol impairment and fatigue effects in accidents suggests that such a device may have a common benefit. Unfortunately, problems with the use of steering reversals as a criterion (Huntley, 1974) and the requirement that each system be individually calibrated for each driver have led to the search for more objective criteria for impairment detection. Attwood's (1979; et al., 1980) use of multivariate methods to predict impairment had led him to the conclusion that reliable "on line" detection of alcohol intoxication using control input measurements, although not totally developed, is feasible.

Hazard warning devices - Existing hazard warning devices utilize radar to detect hazards in the vehicle's path and to sound a warning tone or activate brakes in response. "Non-cooperative" systems refer to vehicle-to-environment radar systems where targets are not specific, as opposed to "cooperative" systems which require a reflective tag on target objects. Using in-depth accident data, Treat (1980) analyzed the benefits of 10 different radar warning and anti-lock braking systems. It was judged that a non-cooperative radar warning system would have had a certain or probable prevention or severity reduction effect in 16.7 percent of the 215 collisions analyzed. The warning system combined with a 4-wheel anti-lock braking system was judged to be potentially beneficial in 38.1 percent of the sample. Wong, et al. (1976) estimated that radar braking could forestall 18 percent of all traffic accidents nationwide, thus preventing 15 percent of all fatalities. According to Flannery, et al. (1979) recent improvements in microprocessor and micro-wave fields have facilitated development of a radar device with significantly improved reliability regarding the detection of hazards in the vehicle's path.

Improved rear lighting - To address the rear impact configuration where the impaired driver is operating the striking vehicle, a number of improvements to rear lighting were considered, including a single center high-mounted stop light, flash rate coding of deceleration, and functional separation of brake and turn signals. Malone, et al. (1978) conducted a field test evaluation of rear lighting systems in which three new configurations were compared with conventional rear lighting. Taxi cab fleets were equipped with one of the various configurations and the incidence of rear-impacts was used as the criterion. The center high-mounted stop light was associated with less than half the rear-end collisons as the control group. The effectiveness was found to increase under nighttime conditions and under conditions where there was almost complete certainty that the stop lights were illuminated just prior to or at impact. Mortimer (1979) conducted a multi-phase study of braking deceleration signals which included a literature review of simulator, driving and accident analytical studies. This was followed by a simulation experiment which provided results consistent with previous experimental studies; viz., "braking deceleration magnitude signals are of modest value to drivers above the information available from conventional braking signals and from primary cues". However, a field test of a specific braking deceleration signal ("Cyberlite") was associated with a large reduction in rear-end crashes.

Several studies have been conducted to compare drivers' responses to different configurations of separated and combined function rear lighting. The most recent study (Attwood, 1978) presents results that are contrary to an earlier study (Mortimer, 1970).

3.3.2 Roadway Modifications

Roadway devices applicable to the objectives of this study include improvements in signs and delineation treatments which provide enhanced information to the driver concerning existing hazards or roadway alignment and roadway alerting devices such as rumble strips or raised pavement markers which upon contact with a vehicle's wheels, cause the vehicle to vibrate and thus alert the driver to a particular stimulus (e.g, hazard with restricted sight distance).

Improved signs - The results of both laboratory and field experiments indicate that alcohol impairs the detection of traffic signs (Shinar, 1978). Furthermore, in one study (Tamburri and Lowden, 1969), sign improvements were found to reduce the incidence of wrong-way accidents on California freeways. Moskowitz, et al. (1976) suggested that the reduced capacity of impaired drivers to interpret roadway communications must be taken into account in the design of signs. Among the specific potential improvements to signs are the following:

1. Improved sign messages

2. Improved conspicuity of signs - Experimental evidence (Hicks, 1976) indicates that increasing sign brightness improved the sign reading behavior of sober and impaired drivers.

3. Active (flashing) displays - This device has been evaluated in a number of different applications including in conjunction with speed reduction signing (Brackett, 1964), in school zones (Brackett, 1965), on curves with high skid potential (Hanscom, 1974), in work zones (Lyles, 1981), among others. Reduction in speed particularly among higher speed vehicles is the effect which has generally been observed.

4. Improved sign placement - The results of numerous eye movement studies (c.f. Naatanen and Summala, 1976; Shinar 1978) can be used to suggest that signs placed in certain locations will have a higher likelihood of being detected by alcohol-impaired drivers than others.

5. Multiple signs of same message.

6. Hazard rating information on signs.

Roadway delineation - Numerous studies have attempted to evaluate the effectiveness of different roadway delineation treatments using both accident and experimental data. According to Stimpson, et al. (1977) edgelines are warranted on all roads with a width of at least 20 feet. The effectiveness of several innovative roadway marking schemes designed to create visual illusions of increased speed, narrowing of the road, and an increase in the perceived angle of a curve was tested in an experimental study conducted by Shinar, Rockwell and Malecki (1980). Each of the treatments had significant but different effects on drivers' approach speeds and on selected visual search parameters. In addition, a recent experimental study was conducted to evaluate the effect of standard and wider road edge markings on the driving behavior of alcohol-impaired and normal subjects. Effectiveness of standard and wide markings was demonstrated by four separate measures of driver path selection, including path range (amount of road used), mean lateral position, positional variability, and driver grouping of lateral position (Nedas, et al., 1981).

Roadway alerting devices - This category includes roadway treatments such as rumble strips or raised markers designed to alert the driver either to lane drift, excessive speed, or to the existence of hazards. Implementation can be both continuous or at specific hazardous locations. Experimental evaluations of rumble strips and raised pavement lines (O'Hanlon and Kelley, 1974) have supported the arousing/alerting potential of these treatments.

3.3.3 Driver Oriented Countermeasures

Although the majority of driver-oriented approaches involve attempts to reduce the incidence of drinking and driving, several approaches are potentially applicable to the objectives of this study. Providing additional training of specific skills at the time of initial licensing or following DWI convictions are included in this category. Lucas, Heimstra and Spiegel (1973) demonstrated that the training of specific skills necessary for estimating passing distances can be accomplished in a simulator. Research cited by Shinar (1978) suggests that drivers can be trained to eliminate potential hazards through development of good visual search habits. Barrett, et al. (1973) evaluated the feasibility of measuring and improving driver decision-making in critical situations.

3.4 Preliminary Evaluation of Prospective Countermeasures

A preliminary evaluation of the specific countermeasures was conducted to establish priorities for testing and development. Countermeasures were evaluated on a number of criteria, including expected effectiveness, state of development, and test feasibility. The rationale and conclusions associated with these criteria are discussed briefly.

3.4.1 Expected Effectiveness

Several considerations were combined to evaluate the prospective countermeasures in terms of their expected effectiveness. First, the magnitude of the specific problem to which the countermeasure was addressed was considered. Since single vehicle road departure accidents associated with problems of lateral vehicle control (tracking) and lowered arousal appear to be the most prevalent result of alcohol-impaired driving, countermeasures addressing these problems were given high priority.

The second consideration was the actual known effect of the prospective countermeasure. Although essentially none of the prospective countermeasures have been adequately evaluated, countermeasures with some demonstrated accident prevention potential were given high priority while approaches with questionable or unknown effect were given lower priority.

3.4.2 State of Development

The amount of developmental effort necessary to implement a prospective countermeasure was considered in the evaluation. Preference was given to fully-developed approaches which are available for immediate implementation over those which would require significant development or fabrication. Accordingly, roadway devices were rated high because of their immediate availability, while performance monitoring devices and driver training systems were judged to require significant developmental effort prior to their implementation.

3.4.3 Test Feasibility

Candidate countermeasures were rated according to the feasibility of conducting preliminary effectiveness tests within the time and budget constraints of the project. Experimental evaluations, using equipped vehicles in a closed-course environment, driving simulation or laboratory studies were selected as the prospective evaluation paradigms. Countermeasures requiring real-world evaluation or accident studies were given low priority.

3.5 Specific Recommendations for Further Research and Development

Within the context of the approach to alcohol countermeasures which attempts to identify and reduce the on-road errors related to accident causation, several countermeasures appear to offer promise, in concept. However, because some of the countermeasures are not totally developed, all issues pertaining to implementation have not been identified. It is also not always possible to predict the future constraints to implementation for treatments which will require several years to develop.

The selection of roadway treatments for Phase III testing was based upon the importance of immediate implementability and use of existing technology. However, the recommendations presented in this section are made based primarily upon their potential for effective reduction of the identified on-road errors. Although not ignored, potential constraints to implementation were considered only secondarily in the development of these recommendations.

3.5.1 Vehicle Modifications

To the extent that alcohol-related accidents are not location specific, in-vehicle monitoring technology, which has the potential of alerting/arousing the driver at the exact time that impairment effects are detected, appears promising. Countermeasures in this category involve two distinct sets of technical issues, one pertaining to the identification of relevant conditions and another pertaining to the transmission of information to the impaired driver.

While the state-of-the-art in hazard identification and impairment detection through on-line monitoring is fairly advanced, there is essentially no existing information which can be used to determine the expected usefulness of various transmissions of information to an impaired driver. The countermeasures in this category vary in the complexity of the transmission as indicated below.

Complexity	Type of Presentation
Simple ↑	Arousing
	Alert to Hazard
	Lane Position or Speed Feedback
↓ Complex	Speed-Distance Information

Laboratory studies which relate information-processing rate to BAC can be used to hypothesize that as BAC increases, the complexity of an information presentation which will be effectively used decreases. While mildly impaired drivers may benefit from relatively complex transmissions, severely impaired drivers probably will only respond to a simple arousing mechanism, if to anything at all. This empirical question is among the most important for the development of countermeasures which address the effects of impairment. Its resolution underlies the potential effectiveness of all countermeasures in this category. The basic recommendation, therefore, is that an empirical evaluation of potential in-vehicle alerting mechanisms be conducted to determine the expected effectiveness of various presentations. Specific recommendations for the two categories of in-vehicle devices are presented below.

(1) Performance monitoring devices - According to Attwood (1979; et al., 1980) impairment detection is feasible. The effectiveness of arousing/alerting the impaired driver is unknown. An experimental study to evaluate the effectiveness of arousing/alerting mechanisms is therefore recommended.

(2) Hazard warning devices - Detection of hazards through use of radar has been implemented as part of existing radar braking technology. Drivers' response to a warning signal, particularly under the influence of alcohol is unknown. Research, using an equipped vehicle to determine responses to hazard warning is therefore recommended. Furthermore, if attempts to alert or warn a driver to the existence of a hazardous situation are not successful, radar braking, an essentially passive system may be the next most promising approach to accident avoidance.

(3) Improved rear lighting - Countermeasures in this category are among the most thoroughly tested in the candidate list. Effectiveness has been demonstrated in laboratory studies and in field evaluations in which rear-impacts were used as a criterion. This leads to the recommendation that no separate developmental work be conducted on improved rear lighting. Where possible, it is recommended that on-going evaluations of rear lighting systems include alcohol involvement as a variable in the analysis.

3.5.2 Roadway Modifications

Of the roadway modifications considered, the roadway alerting devices appear to offer more promise than sign improvements as potential alcohol countermeasures. They are directly applicable to the primary impairment effects identified in Section 2. Furthermore, these countermeasures generally are intended for continuous application along road segments associated with road departure accidents. Experimental evaluations of rumble strips and raised pavement lines (O'Hanlon and Kelly, 1974) have provided perhaps the most important evidence supporting the arousing/alerting potential of these treatments.

An important technical issue in the development of alerting mechanisms concerns the duration of a driver's response to such a treatment. The above referenced study reported that 18.5% of the drivers who impacted shoulder treatments experienced a subsequent lane departure within 5 minutes. The corresponding percentage for drivers not impacting shoulder treatments was 28.6%. It was also reported that all physiological evidence of arousal following impact was gone within 5 minutes (O'Hanlon and Kelly, 1974). A transient effect was also found in a study of pavement markings which create the illusion of increased speed. Initial observed speed reductions had disappeared within 30 days of implementation (Shinar, Rockwell, and Malecki, 1980).

To the extent that roadway delineation treatments can improve tracking performance, they also may be helpful to alcohol-impaired drivers. The evidence provided by Nedas, et al. (1981) suggests a potential improvement in tracking performance. The potential for sign modifications is less clear, particularly since a driver's attention must be directed toward a sign for the information to be obtained. The following specific recommendations are made:

(1) <u>Rumble strips along roadside to alert driver to lane drift</u> - Although effectiveness of such treatments in arousing experimental test drivers has been demonstrated, the duration of the effect is in question (O'Hanlon and Kelly, 1974). Because of the difficulty of conducting preliminary tests with

this countermeasure, an experimental test to determine the duration of alternative alerting treatments including one with a similar effect to rumble strips is recommended.

(2) Rumble strips in roadway to alert drivers to existence of hazard - The immediate arousing potential of rumble strips is supported by O'Hanlon and Kelly's (1974) study. In addition, rumble strips in the roadway are currently used in certain areas to warn drivers of an imminent change in demands (i.e., need to reduce speed). To the extent that hazardous locations with restricted sight distances and requiring a significant speed reduction for safe negotiation can be identified, the use of the treatment is recommended. However, because no specific experimental evaluations were identified, an effectiveness evaluation, preferably involving observation of vehicles on an operating roadway is recommended.

(3) Raised reflectorized delineators to alert drivers to lane drift - The results of a recent cost-effectiveness analysis of alternative roadway delineation treatments (Bali, et al., 1978) recommended that painted centerlines be replaced with raised centerlines where a service life of five years is expected and AADT (Average Annual Daily Traffic) exceeds 3,000. No comparable analyses of raised edge lines were conducted. Because the extent of the use of raised edge lines is unknown, a search of existing information and current implementation practices is recommended.

(4) Pavement markings - The effectiveness of several innovative pavement markings has been demonstrated by Shinar, Rockwell and Malecki (1980). For such countermeasures which function by creating a visual illusion of increasing speed or of a narrowing road, a thorough feasibility study including a determination of potential negative consequences particularly for impaired drivers is recommended. Before implementation is recommended,

certainty must exist that illusions will not cause "overload" and loss of control by impaired or fatigued drivers. Feasibility analyses should also determine the importance of the "transient" nature of the effects. Following this, the feasibility of incorporating such roadway markings in driving simulation scenarios for tests with impaired subjects is recommended.

(5) Improved sign messages - Experimental work is required to determine the types or attributes of sign messages which would be more easily detected by impaired drivers.

(6) Improved conspicuity of signs - Experimental evidence (Hicks, 1976) indicates that increasing sign brightness improves the sign reading behavior of sober and impaired drivers. A determination of the feasibility of changing sign brightness standards is recommended, followed by field implementation and evaluation.

(7) Active (flashing) displays - To the extent that this countermeasure is intended to arouse or alert drivers, development is consistent with one of the major recommended objectives of an alcohol countermeasure project. However, because the importance of hazardous locations in alcohol-related crashes has not been established, the accident-reducing potential of this countermeasure is unknown. It is recommended that any experimental test designed to evaluate alerting mechanisms consider including active displays as an alternative.

(8) Improved sign placement - As a countermeasure intended to increase the likelihood of sign detection, the results of numerous eye movement studies (c.f. Naatanen and Summala, 1976; Shinar, 1978) can be used to determine sign locations which maximize detection probability. Consideration of the reduced capabilities

of impaired drivers is recommended in programs aimed at developing placement guidelines.

(9) Multiple signs of same message - Development of warrants for multiple signs is appropriate for programs to improve roadway communication.

(10) Hazard rating information on signs - Data are needed on the effectiveness of existing hazard rating signs (e.g., advisory speeds) before further development can be recommended. Experimental tests of various in-vehicle hazard warning devices may have implications for the expected use of hazard information on signs by impaired drivers.

(11) Advance warning signs to identify hazards with restricted sight distance - If it can be established that abrupt unexpected changes in the demands of the driving task are related to the causation of single vehicle lane/road departure accidents involving alcohol, the countermeasure may be appropriate for consideration as a means to provide advance warning of hazards.

3.5.3 Driver Oriented Modifications

This category includes proposed additional training of drivers at initial licensing and/or following DWI convictions. The objective of such training would be to develop specific overlearned skills which are robust to the effects of alcohol impairment. An alternative approach involves the training of "state specific" skills which are based upon the reduced capabilities of impaired, fatigued, or elderly drivers. The basic technical problem in either approach involves the identification of specific skills with a known involvement in accident causation. The preponderance of underaroused drivers involved in single vehicle accidents suggests that "alertness" training may be an appropriate endeavor.

The review of available literature identified several demonstrations of the feasibility of training specific skills, such as passing gap estimation (Lucas, et al., 1973) and visual search strategies (Shinar, 1978). One study (Barrett, et al., 1973) involved a comprehensive determination of feasibility of measuring and improving driver decision-making based upon a review of driver training hardware and existing training films. One of the critical decision-making situations involved tracking or lane maintenance. As part of this program, a comprehensive plan for research and development was presented. Further development of driver training should include a comprehensive evaluation of the Barrett, et al., (1973) training and research program within the context of what is currently known about alcohol accident causation. The following specific recommendations are made:

(1) Additional training of selected skills at initial licensing - Although no specific data are presented, Shinar (1978) argues that a large part of the driving population consider themselves experts and consequently resistant to modification of driving habits. Driver improvement through training therefore is expected to be most effective before a person becomes a licensed driver. With the exception of one study (Barrett, et al., 1973) the identification of specific skills for training has not been sufficiently tied to the behavioral errors involved in accident causation especially for alcohol-related crashes. A more thorough feasibility assessment is recommended as a prerequisite for further development of this countermeasure.

(2) Additional training of selected skills following DWI conviction - Although only 10-15% of alcohol accidents involved drivers with previous DWI convictions, overrepresentation in alcohol accidents is extremely high. This suggests that drivers convicted of DWI are especially vulnerable to the

effects of alcohol impairment. The development of a training program for convicted DWIs involves several problems in addition to those discussed above, including the requirement for unlearning of deficient but over-learned skills and the transfer of skills learned in one behavioral state (e.g., sober) to another (alcohol-impaired). In addition to technical development, numerous unresolved issues pertaining to implementation exist for this countermeasure. Therefore, a thorough feasibility evaluation is recommended prior to further development and testing.

4. PRELIMINARY TESTING OF SELECTED ROADWAY COUNTERMEASURES

Based upon the recommendations presented in the previous section, and upon the priorities of NHTSA and FHWA, roadway treatments were selected for evaluation in Phase III of this study. Roadway treatments were selected largely because they would be easy to implement in the real-world and because no significant development would be required. In this section the methodologies, procedures, results and conclusions from two separate experiments are reported. Experiment I was a closed-course evaluation of a rumbling shoulder treatment and raised pavement markers spaced at 40 foot intervals along the center line of a two-lane closed test course. The servo-steering mechanism of the Driver Performance Measurement and Analysis System (DPMAS) (Klein, et al., 1976), was used to simulate the two roadway treatments. Data collection for Experiment I was conducted at the Texas Transportation Institute by the Human Factors Division.

Experiment II was a simulator study conducted by Systems Technology, Inc. (STI) in which subjects responded both to continuous roadway treatments (standard and wide edgelines) and spot treatments implemented in the approach to horizontal curves. The treatments were implemented either electronically and displayed on the CRT or with slides superimposed on the roadway.

4.1 Experiment I - Closed-Course Evaluation of Two Simulated Roadway Treatments

Experiment I was intended to evaluate the potential effectiveness of two related roadway countermeasure concepts, including a rumble shoulder treatment and a raised lane delineator. The major question to be addressed was whether a patterned vehicle vibration, similar to that caused by vehicle contact with a shoulder treatment (e.g., rumble strips, patterned cut grooves, etc.), or with a raised lane delineator (e.g., Bott's dots, reflectorized delineators) would improve the performance and/or increase the level of alertness of drivers under different conditions of alcohol-dosing on a relatively uneventful, nighttime, drive over a simulated rural two-lane unlighted road. A second question concerned the interaction of countermeasure effects and time. Do rumble strips lose their effectiveness with repeated exposure, as a driver habituates to their effects?

4.1.1 Background

Research on the effects of alerting mechanisms on driver performance is scarce. The on-road study of O'Hanlon and Kelley (1974), in which subjects drove an instrumented van over roads with different configurations of rumble strips on the shoulders, is among the few relevant studies. Immediate and long-term responses of the drivers to vehicle contact with the various shoulder treatments were analyzed. It was found that subjects never applied the brakes immediately before, during, or after an alerting event. Similarly, no reliable changes in either EEG α or θ, in heart rate, or in velocity were found immediately following rumble strip contact. Immediate steering wheel responses were also examined and found to be not particularly useful. Only Galvanic Skin Response (GSR) changed consistently with rumble strip contact. Interpreted as heightened arousal, this effect was observed to persist for no longer than five minutes. Despite the lack of identifiable immediate effects, rumble strip contact was found to have a significant effect on the mean time between successive road departures. On roads with rumble strips, the mean time between successive departures was approximately 48 minutes; without any shoulder treatment, it was 12 minutes.

Sugarman and Cozad (1972) reported a significant effect of another type of alerting stimulus (engine failure) on driver performance. In their study, the early occurrence of this emergency event led to improved performance and increased arousal over a four-hour drive. Finally, one additional study was identified which reported reliable improvements in vigilance performance when subjects were exposed to vertical vibration, relative to a control condition (Poulton, 1976). These subjects were exposed to a 5 Hz vibration while performing a dial-monitoring task.

Sumner and Shippey (1977) reported the results of a series of experimental studies through which a roadway rumble treatment was developed and evaluated. Initial laboratory simulation studies were conducted to establish optimal alerting properties. Subjects gave subjective ratings of the noticeability of the various patterns when combined with a normal road noise soundtrack. It was found that a half-second pulse every second gave "the most satisfactory audible alert." Based upon the laboratory studies, roadway treatments were implemented in the road along the approaches to selected hazards. Observational and accident studies were conducted. Although there was some evidence of speed reduction, the effects were generally small or not statistically significant. However, accident data analyses revealed a reduction associated with the rumble treatments.

At two sites, drivers were stopped and given a questionnaire, which asked about their awareness of the alerting stimulation. It was found that 49 percent of the drivers ($N \approx 400$) noticed something unusual with the road surface, while an additional 5 percent noticed something but related it to mechanical failure. When asked to describe what they noticed, 25 percent of the drivers described the effect in terms of noise, 67 percent described it in terms of vibration and the remaining 8 percent saw the treatment but experienced no noise or vibration. The authors concluded that the tactile stimulus was therefore more significant than the auditory component (Sumner and Shippey, 1977).

The available research on the effects of alerting mechanisms suggests that immediate physiological effects of the roadway treatments may be difficult to identify. Longer term behavioral effects, such as the time between successive excursions can be expected to more reliably demonstrate countermeasure effects. Treatments which provide tactile stimulation can be expected to be more noticeable than those which give auditory stimulation.

4.1.2 Hypotheses

Based upon the review of alcohol impairment effects presented in Section 2 and the preceding review of alerting stimulation, the following empirical hypothesis are presented:

1. Driver performance will degrade as BAC increases.

    a. The number and magnitude of lane deviations will increase.

    b. Lateral position variability will increase.

    c. Speed variability will increase.

2. Driver performance is hypothesized to improve under the countermeasure condition.

    a. Road position errors will decrease, including:

        1. Lateral position variability

        2. Number of lane deviations

    b. "Accidents" will decrease.

3. Time between lane departures is expected to increase under countermeasure condition.

4.1.3 Methodology

Design

A within-subjects design was used to evaluate the effectiveness of the selected countermeasures on driving behavior and arousal at different BACs and over time. The main design factors are presented schematically in Figure 1.

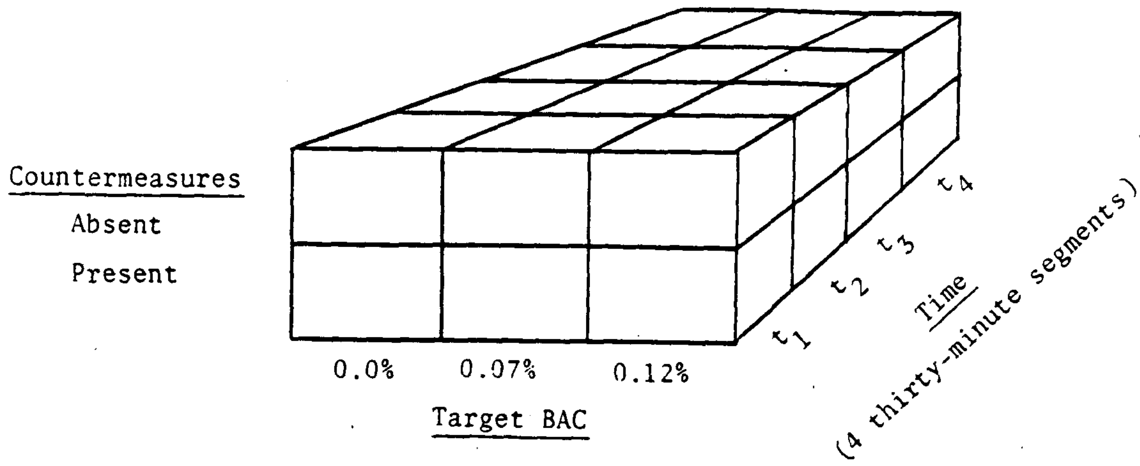


FIGURE 1. - EXPERIMENTAL DESIGN

Apparatus

The testing instrument was the Driver Performance Measure and Analysis System (DPMAS), a completely instrumented 1974 Chevrolet Impala capable of onboard digital recording of driver control and activity measures, vehicle motion variables, and driver psychophysiological measures. The DPMAS is described by Klein, et al. (1976). The vehicle is also equipped with a video system capable of recording the visual record of the path-following actions of the driver. The servo-steering system of the DPMAS was used to simulate the two roadway countermeasure treatments. This system allows movement of the front tires independent of the driver's steering wheel inputs. The movement is produced by an electrohydraulic servo actuator that extends a piston between the pitman arm and relay rod of the steering system. This system is shown in Figure 2. The servo is activated by an external sine wave generator which causes the servo to produce a series of equally-spaced jerks to the steering system. The magnitude of these displacements is controlled by a variable gain circuit in the actuator circuit. The action manifests itself as a series of rapid, small changes in the front tire track, and an audible "shake" of the steering wheel. The sine wave function was selected

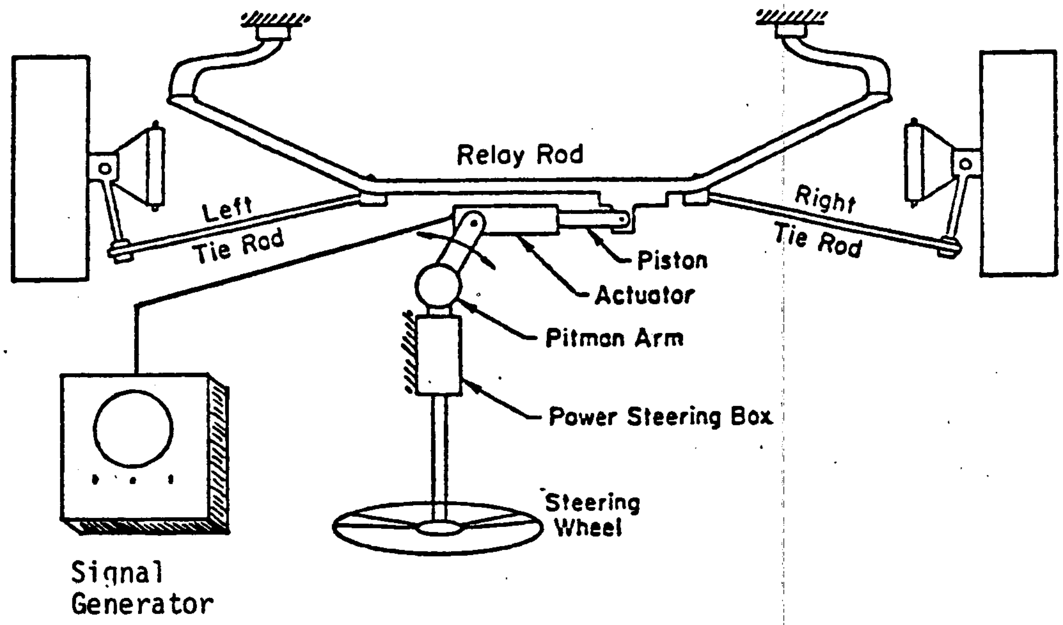


FIGURE 2. - SERVO STEERING SYSTEM

to be 10 HZ to simulate crossing rumble strips spaced 1 foot apart at 40 mph. To evaluate the adequacy of the simulation, a small-scale preliminary experiment was conducted. The results (see Appendix F) revealed no differences in the responses elicited by both the simulated and an actual mockup, rumble strips.

Test Course

A schematic representation of the approximately 3.12 mile test course is presented in Figure 3. The two-lane course was defined by white edge lines and a yellow dashed center line, except on curves with restricted sight-distance, where a no passing zone was defined by double yellow centerlines. Advance warning signs to identify sharp curves were placed on the course, according to the specifications of the Manual on Uniform Traffic Control Devices for Streets and Highways (see Figure 3). The respective straight and curved road mileage on the test course was 1.89 (60.6%) and 1.23 (39.4%) miles.

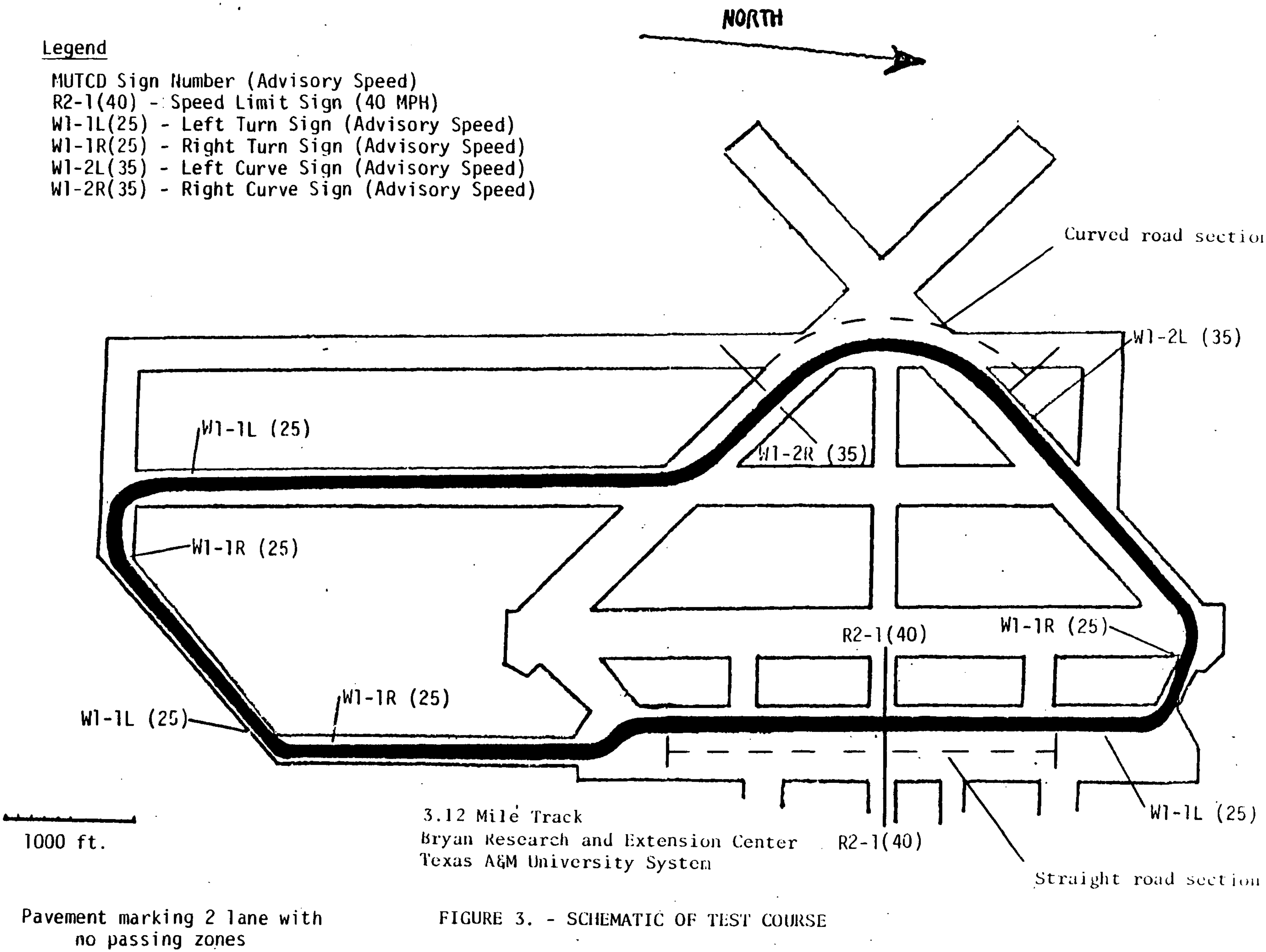


FIGURE 3. - SCHEMATIC OF TEST COURSE

Subjects

Six licensed male drivers, aged 21 to 55 years old, participated in the experiment. Males in this age category are involved in the majority of alcohol-related crashes. The subjects were recruited from TTI employees to minimize recruiting, screening, and session scheduling costs. To ensure that subjects had no previous knowledge regarding the objectives of the experiment, employees of the Human Factors Division (in which the experiment was conducted) were excluded. Participation in the experiment was voluntary. Each subject signed an informed consent form (see Appendix A).

A screening form (Appendix B) was administered to each prospective subject to assess typical drinking behavior. Excessive drinkers or those without sufficient experience to attain the required BAC levels were eliminated through the screening. Use of the screening questionnaire is described in Appendix C. A physical examination was administered by the Texas A&M University Health Center. Use of any drugs or medication which might affect the subject's response to the alcohol dose levels was determined, in addition to the subject's general physical condition (see Appendix D).

Driving Task

In each experimental session, the subject was instructed that his task was to complete a predetermined number of laps of the course. The number of laps (20) was determined from the results of the preliminary data to ensure that all subjects drove for at least two hours per session. Once determined, the task was the same for all subjects. Sessions were conducted under nighttime conditions, between approximately 8 to 11 p.m. Although previous fatigue studies have utilized longer sessions (c.f. Sugarman and Cozad, 1972; O'Hanlon and Kelley, 1974), the use of alcohol-dosed subjects required a shorter task. At pre-established intervals (30 minutes), subjects were instructed to reverse the direction of travel on the course. Subjects were instructed to maintain a constant velocity (40 mph), except on curves, and were instructed to drive as if alone in the vehicle. They also were instructed to keep in the right-hand lane in anticipation of oncoming traffic. The experimenter intervened upon the occurrence of an "accident" or excessive (slow or fast) speed. Accidents were defined as road departures of at least four feet. Excessive speed was defined as a speed outside a 10 mph envelope around the instructed speed (i.e., 35 to 45 mph). Instructions are presented in Appendix E.

Treatments

Each subject completed six experimental sessions (3 BAC levels x 2 countermeasure conditions; see Figure 1). Treatment order was counter-balanced across BAC level and countermeasure treatment to distribute order effects over all cells. In the countermeasure-absent condition, the task was as described above. Deviations from the delineated lane were recorded, but no feedback was provided. For the countermeasure-present condition, the task was the same, with the exception that deviations from the right-hand lane, when recorded by the rear seat experimenter activated the countermeasure mechanism, resulting in vibration of the vehicle. Excursions to the right side resulted in a continuous vibration to simulate a shoulder treatment. Vehicle vibration continued until the wheels returned to the travel lane.* Left side departures into the adjacent lane of the two-lane course resulted in a vibration of short duration to simulate vehicle contact with a raised lane delineation treatment. The vibration characteristics were calibrated to represent the feel of contact with rumble strips on the shoulder of a road. To avoid confounding of effects of vibration duration and frequency, the same pattern was used to

*Activation of the "rumble strips" at the road edge, rather than at some distance from the road edge, is based upon the suggestions of O'Hanlon and Kelley (1974), who argued that drivers should be given the maximum opportunity for recovery following road departure.

simulate both the shoulder treatment and the lane delineation. Only the duration of the vibration was varied. Preliminary work was conducted to match the characteristics of the simulation to actual contact with rumble strips.

Procedures

After screening and medical examination, subjects were given one training session and six experimental sessions. The training session familiarized the subjects with the experimental vehicle and procedures, and allowed collection of the baseline performance and physiological data.

The subjects were picked up and driven to the experimental facility by TTI experimenters. Subjects were instructed not to eat for at least four hours before experimental sessions, and not to consume alcoholic beverages for at least 12 hours before each session. Upon arrival, a Breathalyzer test was administered to ensure that no alcohol had been recently consumed.

Alcohol was administered over a constant time period (1 hour) so that the subject was not aware of the amount received. Dosage was calculated according to the subject's body weight and the desired BAC level (see Figure 1). Vodka mixed with a collins mixer or orange juice was used. The placebo dose (BAC-0.0% condition) consisted of a teaspoon of vodka floated on top of a volume of mixer equal to the liquid volume in the other conditions.

Thirty minutes following the alcohol administration, a breathalyzer reading was taken. When the target BAC was reached, the subject was taken to the DPMAS. Instructions were read during practice session, and psychophysiological recording electrodes were attached to him.

After each experimental session, the subject's BAC level was measured. He remained at the test facility until his BAC was at least below 0.10 percent (the legal definition of intoxication in Texas.) The subject then was provided a meal and driven home by the two experimenters. Upon arriving at the subject's home, one experimenter walked him to the door and made sure he got inside safely. The subject was not released until his BAC was 0.05 percent.

No information about the purpose of the study and uses of the data was provided to any subject until all data collection was completed.

4.1.4 Data Collected

Using the DPMAS, data were collected with both the digital tape recorder and the video system. Table 7 presents the measures available from the digital recorder for the sample group selected for the study*, including both measures of vehicle control behavior and physiological measures. These measures were recorded continuously over each two-hour session. In addition, the DPMAS was equipped with an event marking device, capable of recording a two digit code at selected points on the digital tape. This device was used to identify lane deviations by direction, and to locate them on the course. It was also used by the experimenter to annotate landmarks on the course (e.g., signs), so that the location of the vehicle could be determined at any point on the data tape.

A continuous video record was taken for each experimental run from a forward-looking camera mounted on the roof of the DPMAS. This record was used to verify the occurrence of digitally recorded events and to obtain certain measures which were unavailable from the digital tape. Characteristics of lane deviations including time and distance outside of the travel lane, and lateral position measurements were taken from the video records.

4.1.5 Data Reduction

The reduction of data was a multi-phased process involving a PRIME 750 and an AMDAHL 470 v/8B computer at the Texas A&M University (TAMU). The DPMAS digital tape was unloaded using a program developed at TAMU. The program produced a file on the PRIME 750 for each file recorded by the DPMAS.

*Sample groups are described in Klein, et al. (1976)

TABLE 7. - DPMAS SIGNALS, GAINS, SAMPLE RATES (GROUPS)

Filter Channel	Quantity	Symbol	HI/Low Gain(Bias)	Sample Rate	Comments
1	Steering Wheel Position δ_{sw}	DSW	$\frac{20\ deg}{60\ v}$	20/sec	Positive-right
2	Steering Wheel Rate $\dot{\delta}_{sw}$	DSWD	$\frac{50\ deg/sec}{v}$	20/sec	Positive-right
5	Steer Angle δ_{wT}	DWT	4 deg/v	20/sec	Positive-right
6	Heading Angle Ψ	PSI	$\frac{5\ deg}{20.v}$	20/sec	Neg o Pos -10v +10v
14	Lateral Acceleration a_{Y_I}	AYI	.1 g/v	20/sec	
22	Forward Velocity	VEL	$\frac{10\ mph}{v}$	2/sec	Always Positive stopped = 0
29	EEG Δ (Delta)	EEG1	$\pm$10v FS	5/sec	
30	EEG Θ (Theta)	EEG2	$\pm$10v FS	5/sec	
31	EEG α (Alpha)	EEG3	$\pm$10v FS	5/sec	
32	EEG β (Beta)	EEG4	$\pm$10v FS	5/sec	
35	Heart Rate	HR	20bpm/v	5/sec	
61-63	Distance Traveled X	DIST TRAV FEET	1count/foot	1/sec	Always Positive

Additional processing was performed on the PRIME files to select 30-second windows of data around selected key code events, including all lane deviations and the selected straight and curved road segments for which data were taken on a per lap basis. These data were reduced further through computation of per-second averages for each measure. The reformatted and reduced files were then run with a separate program to produce a log of the key codes found.

The event times produced as part of this log were then used to locate the event on the appropriate video tape to obtain the required video data. Video reduction was done manually with templates on the video screen. Lateral placement was recorded for each second of each 30-second window, while other departure characteristics (time off road, maximum distance off road) were recorded once for each lane deviation. These data were entered directly onto disk files on the AMDAHL. The processed PRIME files were converted to AMDAHL readable files and transferred to the AMDAHL. A merge procedure was performed on the two data files to produce a single file containing all data. Missing data were coded as such.

The complete file was then divided into two files. File "DEVDATA" contained the 30-second averages for all selected variables (see Table 8) for all lane deviations (code = 77, left or 99, right). The "LAPDATA" file contained the same data for the two per lap events which included a straight section (code = 55) and a curved section (code = 66). The selected straight and curved sections are shown in Figure 3.

A third data file was constructed from the DEVDATA file such that one record was defined for each 30-minute data collection segment. In addition to variables defining the experimental conditions (BAC, CM, SEG), the frequency and type (left, right) of lane deviations were recorded.

4.1.6 Results

Missing Data. The original experimental design called for data collection using twelve subjects. However, due to recurrent inclement weather at TTI, course scheduling conflicts, and other problems (e.g., subject sickness) only six subjects were used in the experiment. Furthermore, due to problems of data recording, inability of the PRIME computer to read DPMAS tapes, or runs terminated early, the data from six subjects were incomplete. Each two hour

TABLE 8. - TTI DATA FILE FORMAT (DEVDATA and LAPDATA)

SUB_NO	=	Subject Number (1-6)
RUN_NO	=	Run Number (0-6, 0= Practice)
TBAC	=	Target BAC (0=0.000%; 1=0.07%; 2=0.12%)
ABAC	=	Actual BAC x.xxx%
CM	=	Countermeasure (0=Off; 1=On)
ST	=	Start Time in Seconds of Day
DATE	=	Date of Run
SEG	=	Segment of Run (1-4)
DIR	=	Direction of Travel (0=Clockwise; 1=Counterclockwise)
TNEW	+	Time in Seconds of Day Key Code
CODE	=	Key Code Entered (55 = on straight per lap; 66 = on curve per lap; 77 = left deviation; 99 = right deviation)
INT	=	Intervention by Experimenters (0=None; 1=Yes)
MAX	=	Maximum Positive Deviation from Reference ± X.X
OFF	=	Number of Seconds Outside Lane on Deviation
CONSECT	+	Number of Seconds of Longest Consecutive Deviation
TYPE	=	Type of Location of Last or Present Curve
LOC	=	Reference Location of Last or Present Curve
MV	=	Mean Velocity Over 30 Seconds
SV	=	Standard Deviation of Velocity Over 30 Seconds
MHA	=	Mean Heading Angle Over 30 Seconds
RMHA	=	Root Mean Square of Heading Angle Over 30 Seconds
MLA	=	Mean Lateral Acceleration Over 30 Seconds
SLA	=	Standard Deviation of Lateral Acceleration
XDEV	=	Mean Placements in Feet from Reference Line
STDEV	=	Std. Dev. of Placement in Feet from Reference Line
DIS	=	Distance Traveled in Feet Over 30 Seconds
MSWR	=	Mean Steering Wheel Rate Over 30 Seconds
MEA	=	Mean Amplitude of EEG α Over 30 Seconds
MET	=	Mean Amplitude of EEG θ Over 30 Seconds
MHR	=	Mean Heart Rate Over 30 Seconds
LHR	=	Log (Standard Deviation of Heart Rate) Over 30 Seconds
TLAPS	=	Total Number of Laps Run by Subject This Session

session was divided into four 30-minute segments. The following table shows the number of data collection segments by segment number. In this and the following table, 100 percent refers to complete data from six subjects.

TABLE 9. - TTI DATA COLLECTION - PERCENT COMPLETED SEGMENTS

Segment	Complete		Missing		Total	
	N	%	N	%	N	%
1	35	97.2	1	2.8	36	100.0
2	34	94.4	2	5.6	36	100.0
3	27	75.0	9	25.0	36	100.0
4	14	38.9	22	61.1	36	100.0
Total	110	76.4	34	23.6	144	100.0

Within each segment of an experimental session, five laps of the test course were to be completed. However, due to the above-mentioned problems, segments were occasionally not completed. The following table presents the number of course laps for which data were recorded, by segment. Percentages are based upon the initial goal of 6 subjects x 6 runs x 5 laps/ segment, or 180 total laps per segment.

TABLE 10. - TTI DATA COLLECTION PERCENT LAPS COMPLETED

Segment	Complete		Missing		Total	
	N	%	N	%	N	%
1	152	84.4	28	15.6	180	100.0
2	150	83.3	30	16.7	180	100.0
3	115	63.9	65	36.1	180	100.0
4	67	37.2	113	62.8	180	100.0
Total	484	67.2	236	32.8	720	100.0

Data loss was most prominent in the third and fourth segments (i.e., the second hour) of the experimental sessions. Overall, data was collected in 76 percent of the segments. However, on the average, 4.4 laps were completed per segment (484 laps/110 segments). Overall, 67 percent of the required laps were recorded.

Table 11 presents a summary of the measures in the LAPDATA file. In this table, percent missing pertains to the loss beyond that described above. Therefore, whereas the experimental design called for 720 laps, and 484 were collected, for mean velocity, an additional 15.85 percent of the 484 laps (i.e., 77) had missing or incorrect data.

The table also describes problems encountered with the data, due to the existence of incorrect data. Note that all physiological data were determined to be unreliable.

Statistical model. Given the magnitude of the missing data and the collection of only one of the two blocks required by the latin square design, a very conservative model was chosen for data analysis. Specifically, subject was treated as a fixed rather than a random factor. Although this limits the generalizability of the results, this approach is consistent with the number and highly select nature of the subjects (see Section 4.1.3). Further, the unbalanced nature of the data precluded using the higher order interactions with the subjects factor as the error term as was done with the STI data. Pooled error terms were used to provide better estimates of the main and interaction effects of interest.

Lane deviation frequency. For each segment of the experimental design, a frequency of lane deviations was recorded. These frequencies were transformed to logarithms to reduce the high positive skew (Kirk, 1982) and were analyzed using PROC GLM in SAS (Freund and Littell, 1981). This approach was selected because of the unbalanced nature of the data set. PROC GLM computes a corrected total sum of squares using an estimable functions method (Freund, 1980) to adjust for missing data. This procedure utilizes a deflated number of degrees of freedom since the calculated sums of squares are only an approximation of a completely balanced design. In the following ANOVA source tables, therefore, degrees of freedom differ, according to the amount of missing data. Abbreviated source tables for the logarithms of left and right lane deviation frequency are presented in Tables 12 and 13, respectively.

TABLE 11. - LAPDATA SUMMARY

Dependent Variable	Percent Missing	Mean	Deviation	Range			Comments
Mean Velocity	15.85	38.0012	4.2632	25.4000	to	46.8000	negative values eliminated from data base
Standard Deviation of Velocity	15.85	1.1840	0.9666	0.0824	to	14.9480	eliminated if mean velocity negative
Mean Heading Angle	13.06	-0.9600	22.5116	-38.8550	to	38.9210	not used since desired path could not be defined
Root Mean Square of Heading Angle	13.06	577.8375	393.9392	2.22723	to	1514.8000	
Mean Lateral Acceleration	13.06	0.0125	0.0671	-0.1734	to	0.1163	eliminated due to frequent occurrences of negative acceleration values
Standard Deviation of Lateral Acceleration	13.06	0.0336	0.0296	0.0041	to	0.1337	
Lateral Position	6.63	1.9139	0.6294	-0.1200	to	3.9200	used without editing
Standard Deviation of Lateral Position	6.63	0.5976	0.2286	0.2030	to	2.7130	used without editing
Distance Traveled	13.06	2726.2336	10219.1691	0.0000	to	101270.0000	eliminated as not of interest and presence of extreme scores, e.g., 0.0000
Mean Steering Wheel Rate	13.06	-5.0129	5.0000	-29.7630	to	5.2490	eliminated because of apparent miscalibration, i.e., high incidence of negative values

TABLE 11. - LAPDATA SUMMARY

(Continued)

Dependent Variable	Percent Missing	Mean	Standard Deviation	Range	Comments
Mean Amplitude EEG α	13.06	38.1299	221.9837	-0.1264 to 1811.0000	eliminated because of extreme scores, i.e., negative values
Mean Amplitude EEG θ	13.06	0.5617	8.5431	-0.3307 to 177.6900	eliminated because of extreme scores, i.e., negative values
Mean Heart Rate	25.70	84.1829	18.5928	40.1510 to 163.4000	eliminated because of extreme values, e.g., $>$ 150
Heart Rate Variability*	26.11	1.3685	1.0658	-2.3619 to 4.3261	eliminated because of extreme values., e.g., $<$0.

*log (standard deviation of heart rate)

TABLE 12.- LOG OF LEFT LANE DEVIATION FREQUENCY - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	1.63	15.53	.000
Countermeasure	(C)	1	0.08	0.80	.375
Segment	(S)	3	0.07	0.66	.581
B x C		2	0.26	2.47	.091
B x S		6	0.05	0.45	.840
C x S		3	0.01	0.06	.974
B x C x S		6	0.03	0.33	.918

TABLE 13. - LOG OF RIGHT LANE DEVIATION FREQUENCY - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	1.34	18.33	.000
Countermeasure	(C)	1	0.01	0.07	.787
Segment	(S)	3	0.23	3.17	.029
B x C		2	0.06	0.76	.473
B x S		6	0.08	1.08	.382
C x S		3	0.05	0.69	.564
B x C x S		6	0.07	1.02	.420

Location of lane deviations. Table 14 presents the lane deviation frequency categorized by the type of road (straight versus curve) on which the deviation occurred. Deviations are also categorized by BAC.

TABLE 14. - LANE DEVIATION LOCATION BY BAC

	Curve		Straight		Total	
BAC	N	%	N	%	N	%
BAC1 (0.00%)	35	89.7	4	10.3	39	100.0
BAC2 (0.07%)	107	87.0	16	13.0	123	100.0
BAC3 (0.12%)	215	74.7	73	25.3	288	100.0
Total	357	79.3	93	20.7	450	100.0

Deviations occurred primarily on curved road sections, with a slight reduction in percentages as BAC increased. Table 15 compares the percentages of straight and curved road lane deviations with the respective percentages of straight and curved road mileage on the test course to obtain a measure of overrepresentation.

TABLE 15. - OVERREPRESENTATION OF DEVIATION LOCATIONS

	Straight	Curve
% Deviations	20.7	79.3
% Course Mileage	60.6	39.4
Overrepresentation Ratio[1]	0.34	2.01

[1] Ratio >1 implies overrepresentation, i.e., a percentage of deviations greater than would be expected by course mileage (exposure) alone.

The percentage of curved-road deviations is approximately twice (2.01) the percentage which would be expected on the basis of course mileage (exposure) alone.

Table 16 presents the distribution of deviation locations by countermeasure presence alone.

TABLE 16. - LOCATION OF LANE DEVIATIONS BY BAC AND COUNTERMEASURE PRESENCE

	Countermeasure							
	Absent				Present			
	Curve		Straight		Curve		Straight	
BAC	N	%	N	%	N	%	N	%
BAC1 (0.00%)	7	87.5	1	12.5	28	90.3	3	9.7
BAC2 (0.07%)	62	90.0	7	10.0	45	83.3	9	16.7
BAC3 (0.12%)	123	71.1	50	28.9	92	80.0	23	20.0
Total	192	76.8	58	23.2	165	82.5	35	17.5

Overall, the presence of the countermeasure treatments was associated with a reduction in the percentage of deviations which occurred on the straight roads, and a corresponding increase in the percentage of deviations which occurred on curves.

Accident frequency. When a lane deviation became so extreme as to warrant experimenter intervention, an "accident" was recorded. In all of the sessions only nine such events were recorded. All nine occurred in the high BAC (BAC3) condition with eight occurring on curves and one on a straight road segment. In addition, eight of the nine occurred in the no countermeasure condition.

Characteristics of lane deviations. For each lane deviation, the video record was used to determine the time (in seconds) the vehicle was outside the travel lane and the maximum lateral distance (in feet) the vehicle deviated from the travel lane. Since lane deviations did not occur with equal frequency in each cell of the experimental design, the data collected during lane deviation events were analyzed by PROC GLM in SAS, using the same adjustments for unequal cell frequencies as described above. In addition, log transforms (Kirk, 1982) were applied to reduce the high positive skew associated with the underlying distributions in the cells of the model. Before the transform, one was added to each value of the variable to move the distribution away from zero. For each variable, separate ANOVAs were computed for left and right lane deviations. Abbreviated source tables are presented in Tables 17-20.

TABLE 17. - LOG OF MAXIMUM DISTANCE OFF ROAD FOR LEFT DEVIATIONS - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.005	0.32	.725
Countermeasure	(C)	1	0.001	0.10	.749
Segment	(S)	3	0.02	1.16	.337
B x C		2	0.006	0.39	.679
B x S		6	0.01	0.62	.710
C x S		3	0.005	0.33	.809
B x C x S		5	0.03	1.78	.117

TABLE 18. - LOG OF MAXIMUM DISTANCE OFF ROAD FOR RIGHT DEVIATIONS - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.02	0.99	.372
Countermeasure	(C)	1	0.02	1.13	.290
Segment	(S)	3	0.007	0.30	.825
B x C		2	0.02	1.03	.359
B x S		5	0.007	0.34	.887
C x S		3	0.005	0.25	.863
B x C x S		3	0.02	0.86	.467

TABLE 19. - LOG OF TIME OFF ROAD FOR LEFT DEVIATIONS - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.29	6.87	.001
Countermeasure	(C)	1	0.12	2.98	.086
Segment	(S)	3	0.09	2.15	.093
B x C		2	0.07	1.62	.200
B x S		6	0.02	0.53	.788
C x S		3	0.03	0.65	.583
B x C x S		5	0.09	2.08	.069

TABLE 20. - LOG OF TIME OFF ROAD FOR RIGHT DEVIATION - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.06	1.60	.206
Countermeasure	(C)	1	0.01	0.31	.576
Segment	(S)	3	0.02	0.53	.664
B x C		2	0.03	0.69	.505
B x S		5	0.09	2.34	.043
C x S		3	0.02	0.42	.745
B x C x S		3	0.15	3.75	.012

For each two successive lane deviations on the same side of the road, a time was computed to represent the time between successive deviations. Here again, the data were transformed to logarithm values to reduce the high positive skew. Separate ANOVAs were computed for left and right deviations. Source tables are presented in Tables 21 and 22.

Overall driving performance. Effects of alcohol level and countermeasure presence on measures of general driving behavior were determined from data taken from a selected straight and curved segment of the test course. For each lap of the course, two 30-second samples were taken. The data were reduced so that a single value for the 30-second sample was used in the analysis. Although a number of performance measures were recorded, initial examination of the data (see Table 11) led to the decision to eliminate several of the measures. Analyses were conducted using the following measures:

- Mean velocity
- Standard deviation of velocity
- Mean lateral position
- Standard deviation of lateral position

For each variable, separate ANOVAs were computed for straight and curved segments. Source tables for the eight ANOVAs appear in Tables 23 to 30.

TABLE 21. - LOG OF TIME BETWEEN SUCCESSIVE LEFT DEPARTURES - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	4.57	21.11	.000
Countermeasure	(C)	1	0.79	3.67	.057
Segment	(S)	3	0.51	2.36	.071
B x C		2	1.23	5.68	.004
B x S		6	0.46	2.14	.050
C x S		3	0.37	1.71	.165
B x C x S		5	0.26	1.19	.317

TABLE 22. - LOG OF TIME BETWEEN SUCCESSIVE RIGHT DEPARTURES - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	2.32	9.68	.000
Countermeasure	(C)	1	0.12	0.52	.472
Segment	(S)	3	0.15	0.61	.613
B x C		2	0.09	0.37	.690
B x S		6	0.14	0.60	.734
C x S		3	0.12	0.51	.680
B x C x S		4	0.16	0.67	.614

TABLE 23. - MEAN VELOCITY ON STRAIGHT ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	3.36	0.78	.458
Countermeasure	(C)	1	18.04	4.21	.041
Segment	(S)	3	12.12	2.83	.038
B x C		2	16.20	3.78	.024
B x S		6	4.91	1.15	.335
C x S		3	16.12	3.76	.011
B x C x S		6	5.05	1.18	.317

TABLE 24. - MEAN VELOCITY ON CURVED ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	135.51	23.24	.000
Countermeasure	(C)	1	38.90	6.67	.010
Segment	(S)	3	9.03	1.55	.200
B x C		2	21.66	3.71	.025
B x S		6	13.83	2.37	.029
C x S		3	16.21	2.78	.040
B x C x S		6	0.75	0.13	.993

TABLE 25. - LOG OF STANDARD DEVIATIONS OF VELOCITY ON STRAIGHT ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	1.81	31.63	.000
Countermeasure	(C)	1	0.01	0.20	.657
Segment	(S)	3	0.04	0.76	.520
B x C		2	0.32	5.53	.004
B x S		6	0.02	0.37	.896
C x S		3	0.12	2.11	.096
B x C x S		6	0.11	1.99	.066

TABLE 26. - LOG OF STANDARD DEVIATION OF VELOCITY ON CURVED ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.51	10.03	.000
Countermeasure	(C)	1	0.02	0.40	.528
Segment	(S)	3	0.36	7.03	.000
B x C		2	0.02	0.42	.655
B x S		6	0.05	0.96	.451
C x S		3	0.01	0.29	.835
B x C x S		6	0.10	1.91	.077

TABLE 27. - MEAN LATERAL POSITION ON STRAIGHT ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.44	2.30	.102
Countermeasure	(C)	1	0.85	4.39	.037
Segment	(S)	3	11.83	61.22	.000
B x C		2	0.30	1.53	.217
B x S		6	0.91	4.72	.000
C x S		3	0.47	2.45	.062
B x C x S		6	0.39	2.00	.064

TABLE 28. - MEAN LATERAL POSITION ON CURVED ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.79	3.42	.034
Countermeasure	(C)	1	0.12	0.54	.462
Segment	(S)	3	17.43	75.72	.000
B x C		2	0.26	1.13	.323
B x S		6	0.53	2.28	.035
C x S		3	0.95	4.12	.007
B x C x S		6	0.68	2.95	.008

TABLE 29. - LOG OF STANDARD DEVIATION OF LATERAL POSITION ON STRAIGHT ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.37	25.40	.000
Countermeasure	(C)	1	0.04	3.07	.081
Segment	(S)	3		7.81	.000
B x C		2	0.12	1.27	.281
B x S		6	0.04	2.67	.015
C x S		3	0.02	1.20	.308
B x C x S		6	0.02	1.09	.368

TABLE 30. - LOG OF STANDARD DEVIATION OF LATERAL POSITION ON CURVED ROAD - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
BAC	(B)	2	0.60	41.32	.000
Countermeasure	(C)	1	0.06	4.03	.046
Segment	(S)	3	0.01	0.81	.493
B x C		2	0.10	7.19	.001
B x S		6	0.03	1.88	.084
C x S		3	0.02	1.20	.311
B x C x S		6	0.02	1.42	.207

4.1.7 Interpretation of Results

Interpretation of the results for the TTI DPMAS data was at times difficult due to the high percentage of missing data, the small number of subjects run, and the high variability in the data collected. These factors combined to reduce the power of the analyses for detecting reliable differences. As a result, many of the effects are not statistically significant. However, the direction of the trends is often interpretable, and therefore where possible, non-significant differences are presented as suggestive, with caveats relating to their reliability.

A second problem of interpretation relates to the frequent use of logarithmic transformations in the analyses. The log transforms were used to reduce the high positive skews of many of the dependent measures. The resulting log values are more normally distributed. However, the mean values of the log distributions generally do not equal the corresponding means of the untransformed data. Since the ANOVA and post hoc analyses used the log means, interpretation of differences among the original, untransformed means is not appropriate. Interpretation of log means, however, is difficult because the original units are lost and the magnitude of change is difficult to determine from logarithms. To retain the original units and be consistent with the ANOVAs, the anti-logs of the ANOVA cells means are used to demonstrate magnitudes of effects. These values will generally be less than the original cell means because the original means are from positively skewed data and thus cannot be expected to represent the actual central tendency of the data.

In the section of the report, the effects of alcohol on lane deviation frequency, deviation characteristics, and overall driving performance are presented first, followed by the effects of the roadway treatments. The effects of driving time are then considered.

Alcohol. Of all the factors in the experiment, the effects of alcohol were strongest and most consistent. A highly significant effect of alcohol was found for both left and right lane deviation frequency (see Figure 4). According to Scheffé post hoc analyses, all means for right deviation frequency were significantly different from each other, indicating a progressive increase with BAC. For the left deviations, however, there was a reliable difference only between the sober (BAC1) and the high BAC (BAC3) conditions. "Accident" occurrence, although relatively infrequent, appeared also to be a high BAC phenomenon. All nine recorded "accident" events occurred in the BAC3 condition.

Among the categories of measures considered, the characteristics of lane deviations were least influenced by alcohol. The maximum lateral distance outside the lane for both left and right deviations (Tables 17 and 18) was not significantly influenced by alcohol level. The cell means for this measure did increase slightly from approximately 0.8 feet (BAC1) to 1.1 feet (BAC3) for left deviations, and 0.7 (BAC2) to 1.0 feet (BAC3) for right deviations.

Time (in seconds) outside the travel lane per deviation exhibited a significant alcohol effect for left deviations, but not for right deviations (Tables 19 and 20). According to Scheffé post hoc analyses, there was a reliable difference only between the low and high BAC conditions. The respective means for the three BAC groups are as follows:

Group	BAC	Mean Time Off Road (Seconds) for Left Deviations
BAC1	0.00%	3.0
BAC2	0.07%	3.4
BAC3	0.12%	4.7

Related to lane deviation frequency is the time between successive deviations. For both left and right deviations, the alcohol effect on this variable was highly significant (Tables 21 and 22). The cell means are presented in Figure 5. Scheffé post hoc analyses revealed reliable differences for left deviations between the low and high BAC levels (BAC2 vs BAC3). For right deviations all three BAC levels were significantly different from each other.

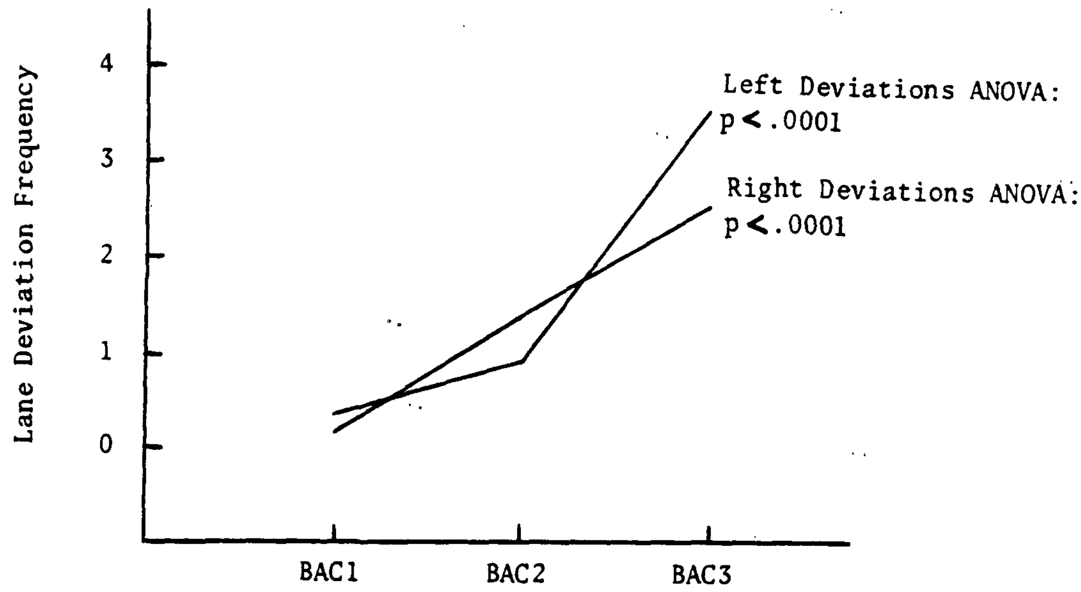


FIGURE 4. - LANE DEVIATION FREQUENCY BY BAC CONDITION

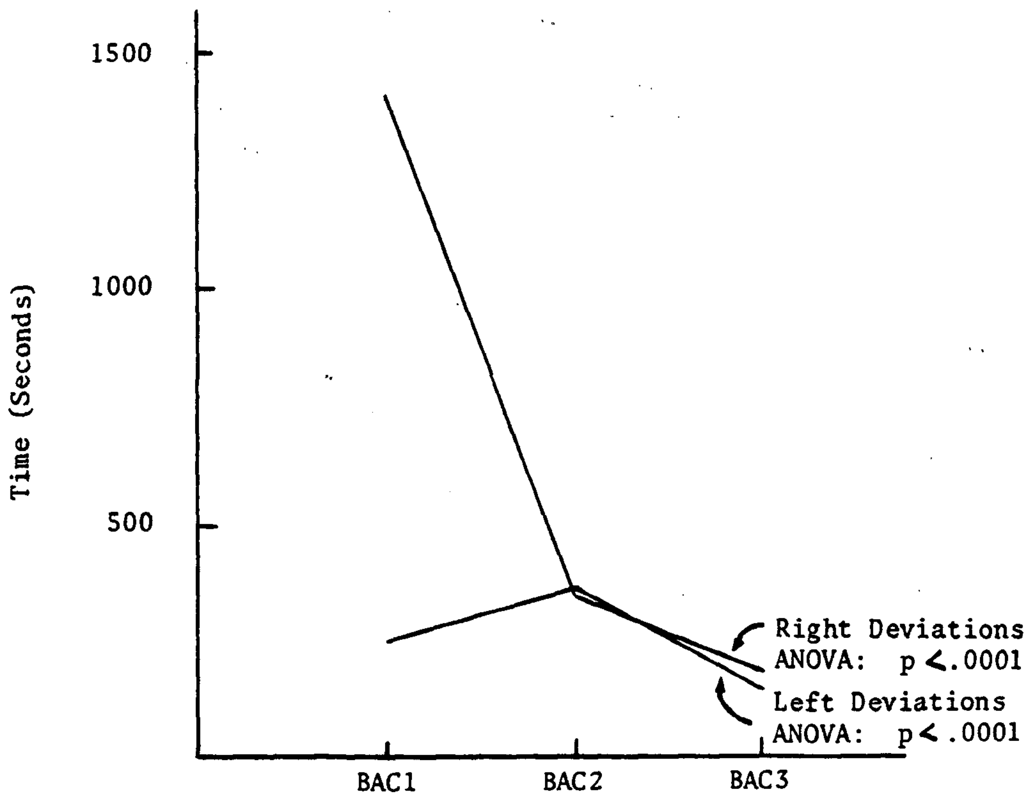


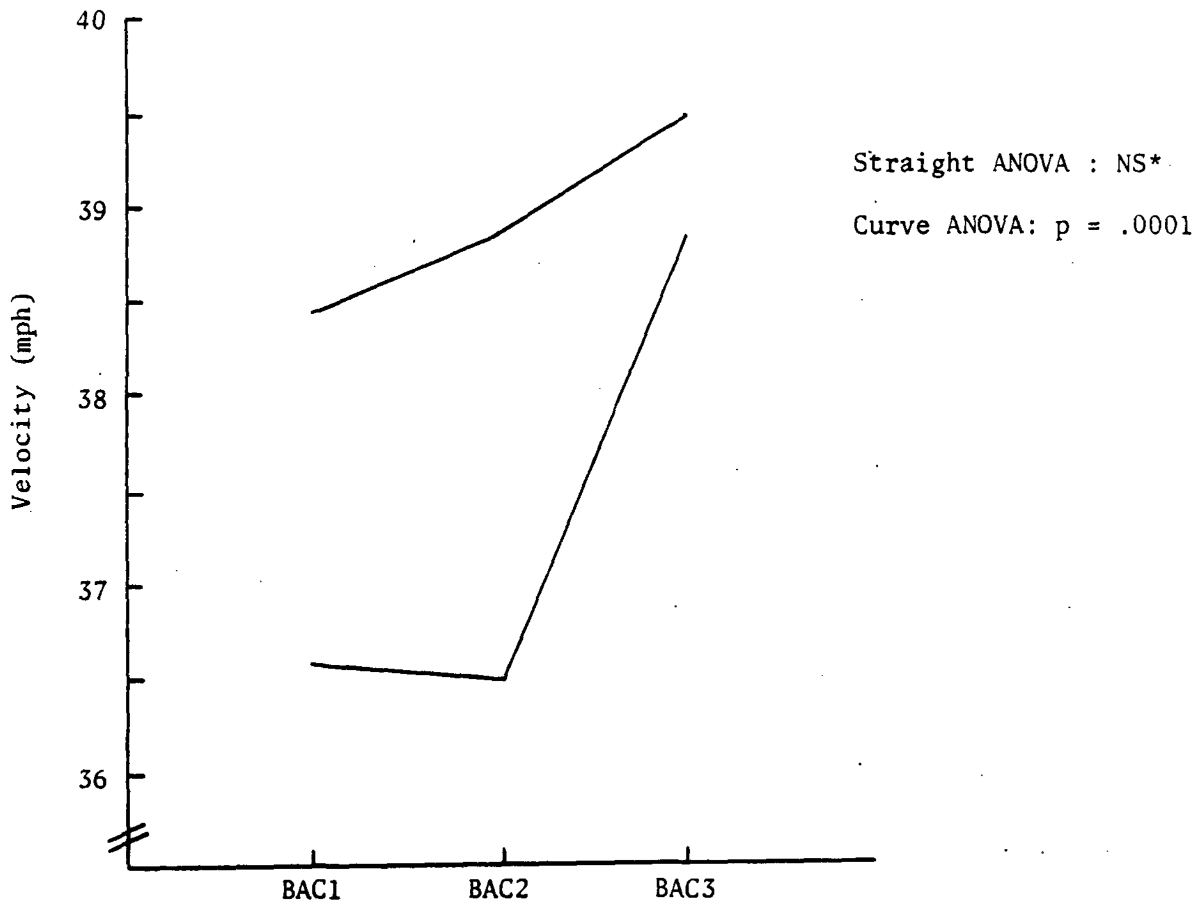
FIGURE 5. - TIME BETWEEN SUCCESSIVE SAME SIDE DEVIATIONS BY BAC

From Figure 5 it is apparent that the greatest difference between right and left deviations is associated with the sober (BAC1) condition. Because in this condition the frequencies for both left and right deviations were extremely small (i.e., less than one per 30-minute segment; Figure 4), each individual deviation had relatively large impact on the time between successive deviations. Values on this measure varied from 0 to almost 6000 seconds, the latter value approaching the length of the two-hour (7200 second) experimental session.

Four measures of general driving behavior were examined. Separate ANOVAs were computed for straight and curved road sections (Tables 23-30). Alcohol effects were significant for six of the eight ANOVAs. The effect of alcohol on mean velocity is shown in Figure 6. At all BAC levels, straight road speeds were faster than speeds on the curved road section. The alcohol main effect on the straight road was not statistically reliable (Table 23), but the cell means do reflect a slight speed increase with increasing BAC. Curved road velocity exhibited a significant alcohol effect (Table 24), reflecting an overall increase of 2.4 mph between the BAC2 and BAC3 conditions. Scheffé post hoc analyses revealed no difference between the speeds associated with BAC1 and BAC2 conditions, which were both significantly slower than the mean velocity at BAC3.

The effects of alcohol on speed variability are shown in Figure 7. For both the straight and curved road sections, speed variability increased with BAC. Scheffé post hoc analyses showed that for the straight road, all three means were different, whereas for the curved road, the two alcohol conditions (BAC2 and BAC3) were grouped and both different from the sober condition (BAC1).

Although there was no reliable alcohol main effect on the mean lateral position for the straight road, the effect was significant for the curved road. These means are shown in Figure 8. On the curved road, as BAC increased, distance from the centerline increased. Post hoc Scheffé tests revealed that only the difference between the two extreme conditions (BAC1 and BAC3) was significant. This indicates a relatively weak effect of alcohol.



*NS indicates that the effect is not significant.

FIGURE 6. - MEAN VELOCITY ON CURVED AND STRAIGHT ROAD BY BAC

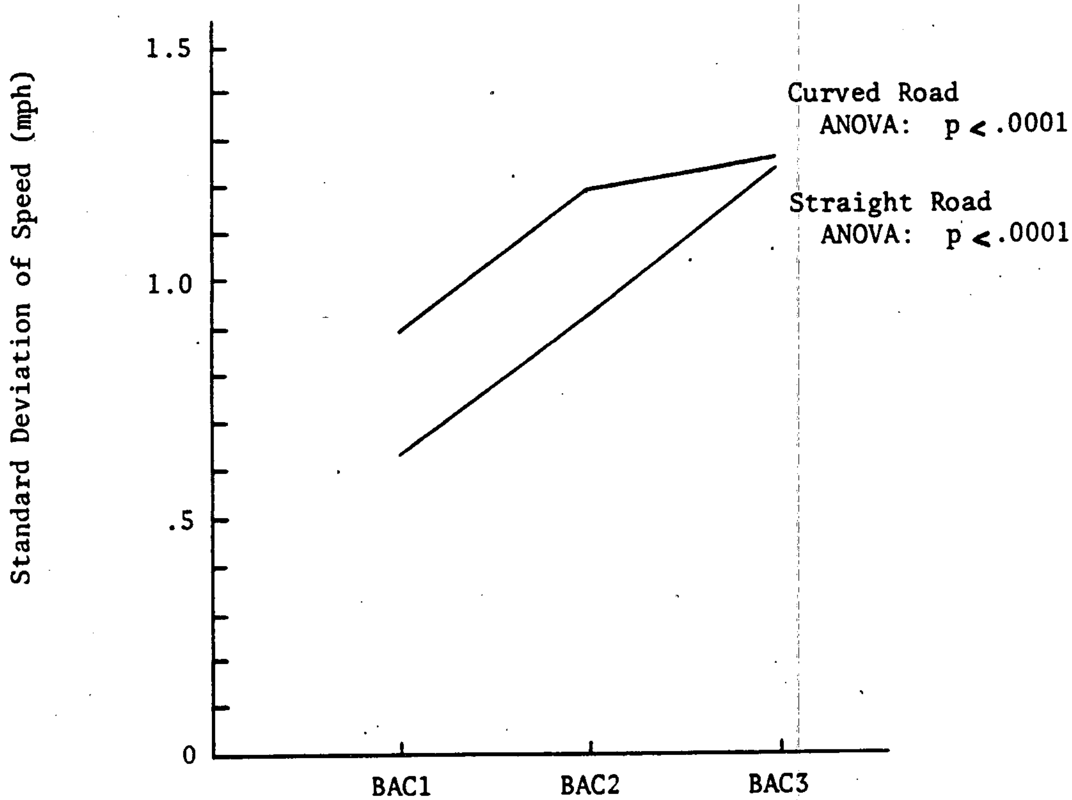
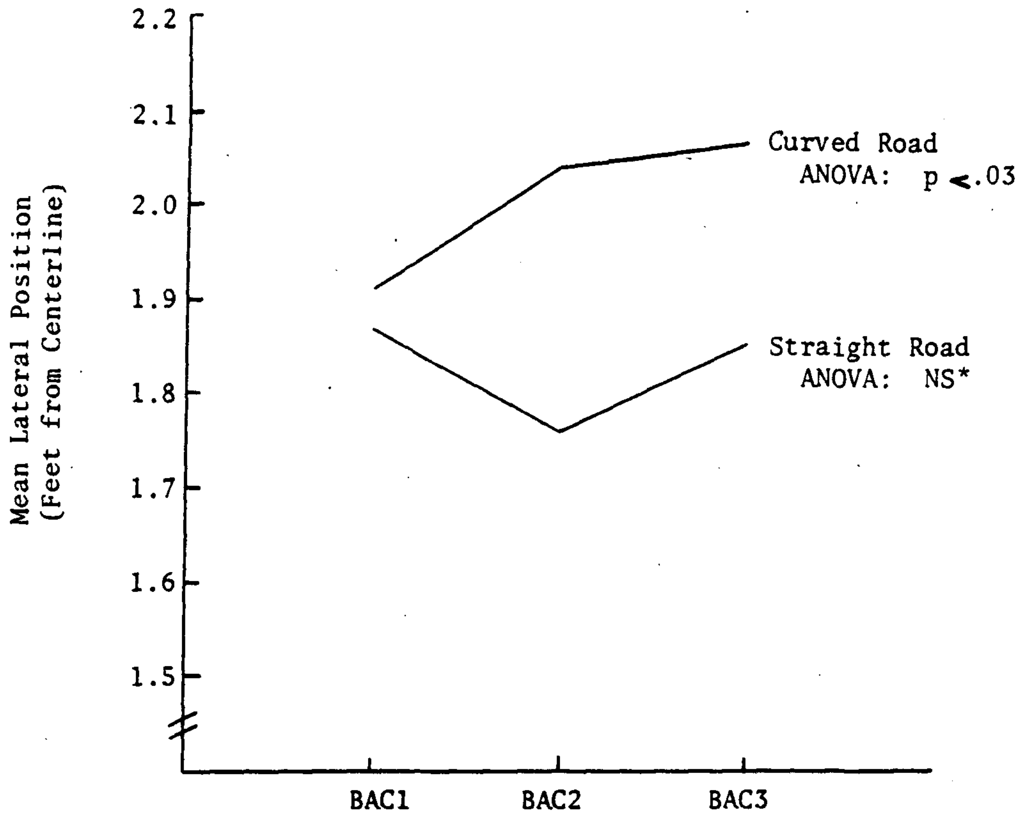


FIGURE 7. - STANDARD DEVIATION OF SPEED BY BAC FOR STRAIGHT AND CURVED ROADS



*NS indicates that the effect was not significant.

FIGURE 8. - MEAN LATERAL POSITION BY BAC ON STRAIGHT AND CURVED ROAD

The log of the standard deviation of lateral position was significantly influenced by BAC for both the straight (Table 29) and curved road (Table 30) sections. For each road type, all means were significantly different (Scheffé post hoc tests) indicating a progressive increase in lane position standard deviation with BAC (see Figure 9).

The effects of alcohol are summarized in Table 31. The magnitudes of the significant effects are presented in Tables 32 and 33.

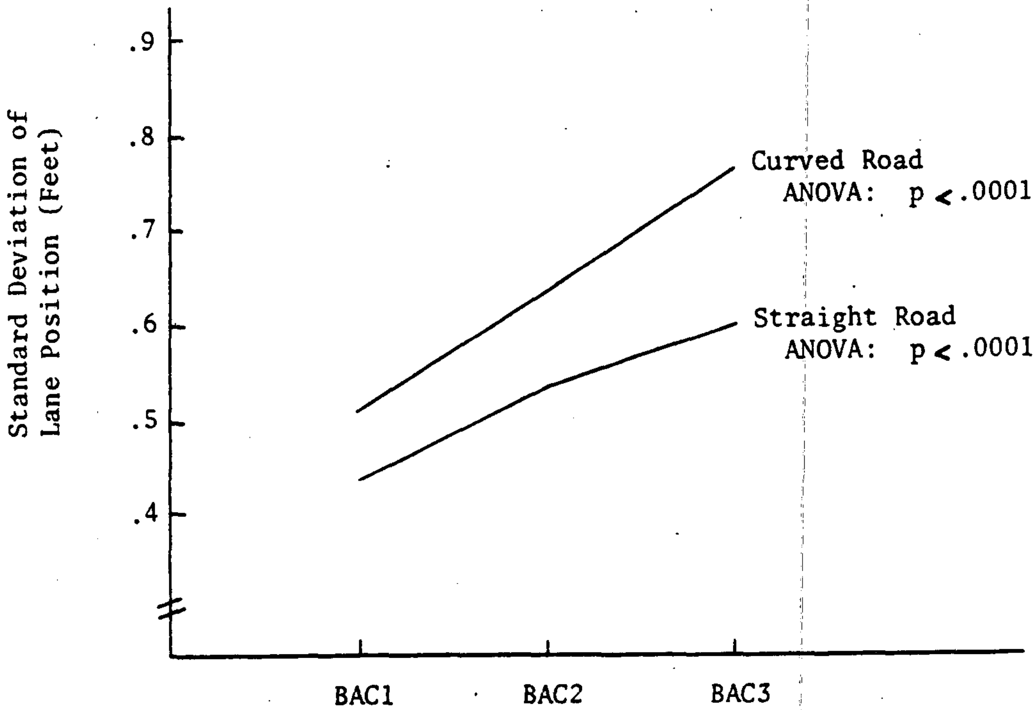


FIGURE 9. - STANDARD DEVIATION OF LATERAL POSITION BY BAC ON CURVED AND STRAIGHT ROAD

TABLE 31. - SUMMARY OF ALCOHOL EFFECTS

Measure	Alcohol Effect	Interpretation
Lane deviation frequency:		
left	Yes	increase at high BAC
right	Yes	progressive increase with BAC
Maximum lateral distance off road:		
left	No	
right	No	
Time off road:		
left	Yes	increase at high BAC
right	No	
Time between deviations:		
left	Yes	decrease at high BAC
right	Yes	progressive decrease with BAC
Mean velocity:		
straight	No	
curve	Yes	increase at high BAC
Standard deviation of velocity:		
straight	Yes	progressive increase with BAC
curve	Yes	increase at low and high BAC
Mean lateral position:		
straight	No	
curve	Yes	small increase at high BAC (move toward centerline)
Standard deviation of lateral position:		
straight	Yes	progressive increase with BAC
curve	Yes	progressive increase with BAC

TABLE 32. - MAGNITUDE OF SIGNIFICANT ALCOHOL EFFECTS (LANE DEVIATION FREQUENCY AND CHARACTERISTICS)

Measure	BAC1	BAC2	BAC3	Diff.	% Change	Unit	Interpretation
Lane Deviation Frequency:							
Left	0.39		3.53	3.14	805	Deviations per 30 minute segment	increase significant at BAC3 only, BAC1 not different from BAC2
		0.95	3.53	3.58	272		
Right	0.25	1.37		1.12	448		progressive increase, all means different
		1.37	2.55	1.18	86		
	0.25		2.55	2.30	920		
Time Off Road: Left Deviations	3.00		4.70	1.70	57	Seconds	increase significant at BAC3 only, BAC1 not different from BAC2
		3.40	4.70	1.30	38		
Time Between Deviations:							
Left	251.8		136.9	-114.9	-46	Seconds	decrease significant at BAC3 only, BAC1 not different from BAC2
		372.7	136.9	-235.8	-63		
Right	1410.1	360.0		-1050.1	-74		progressive decrease, all means different
		360.0	183.8	-174.2	-49		
	1410.1		183.8	-1226.3	-87		

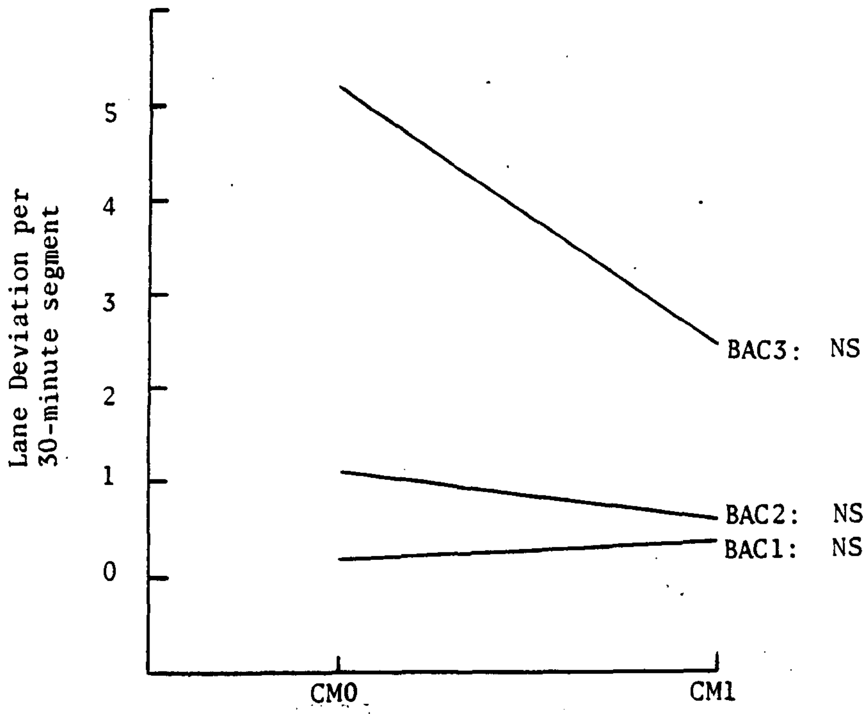
TABLE 33. - MAGNITUDE OF SIGNIFICANT ALCOHOL EFFECTS
(DRIVING PERFORMANCE MEASURES)

Measure	BAC1	BAC2	BAC3	Diff.	% Change	Unit	Interpretation
Mean Velocity:							
Curve	36.6		38.9	-2.3	-6	mph	decrease at BAC2, increase
		36.5	38.9	-2.4	-7		at BAC3
Standard Deviation of Velocity:							
Straight	.63	.92		.29	46		progressive increase with BAC,
		.92	1.23	.31	34		all means different
	.63		1.23	.60	95		
Curve	.89	1.19		.30	34	mph	increase with BAC, BAC2 not
	.89		1.25	.36	40		different from BAC3
Mean Lateral Position:							
Curve	1.92		2.06	.14	7	Feet	increase from BAC1 to BAC 3 only
Standard Deviation of Lateral Position:							
Straight	.43	.53		.10	23		progressive increase with BAC,
		.53	.60	.07	13		all means different
	.43		.60	.17	40		
Curve	.51	.63		.12	24	Feet	progressive increase with BAC,
		.63	.77	.14	22		all means different
	.51		.77	.26	51		

Countermeasure Effects. Results from the two ANOVAs computed for left and right lane deviation frequency (Tables 12 and 13) indicated that the rumbling treatments had no overall effect on deviation frequency. However, although not statistically reliable, the BAC x Countermeasure interaction for left deviations indicated a positive countermeasure effect at the high BAC condition (BAC3). At the BAC3 condition, the reduction associated with Countermeasure presence (CM1) was almost 50 percent or 3 deviations per 30 minute time segment. Means for this effect are shown in Figure 10.

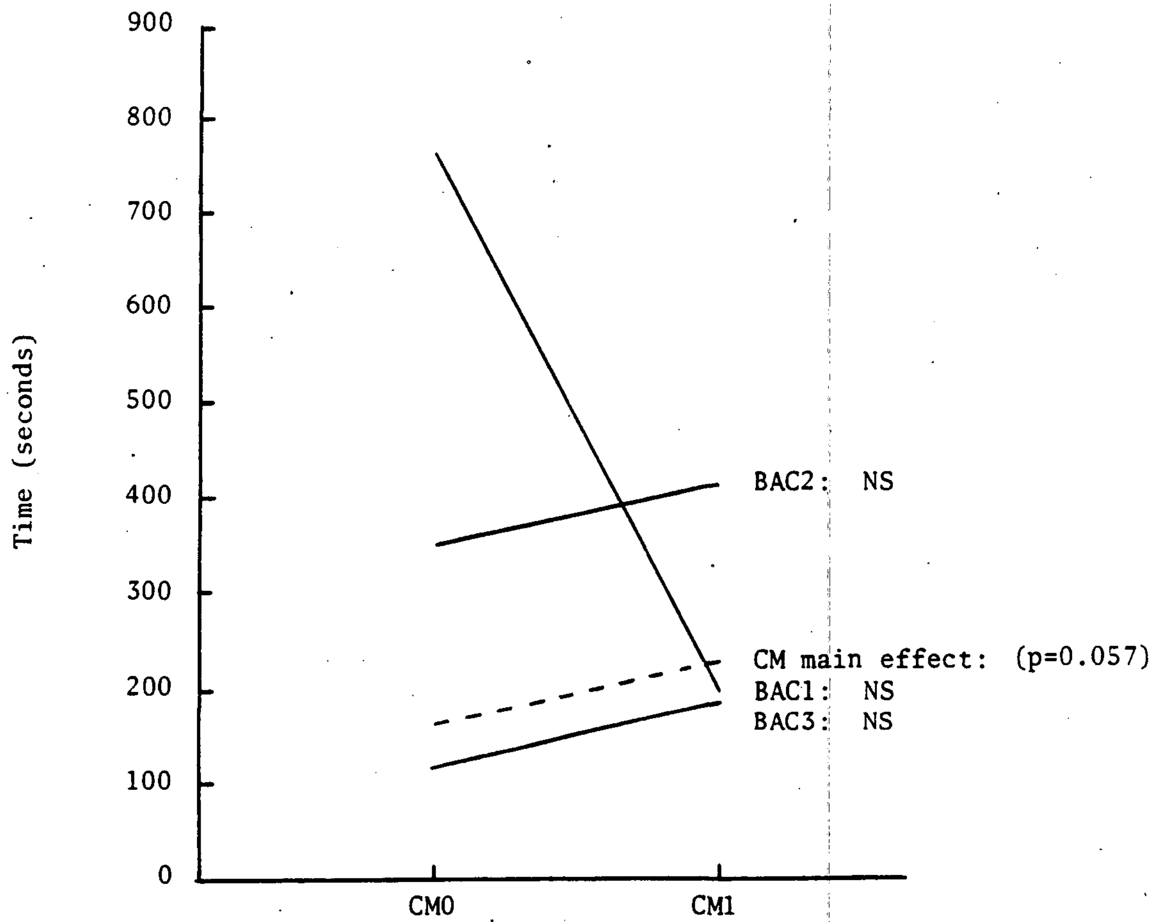
The maximum lateral distance off the road per deviation for both left and right side departures was not influenced by the countermeasure presence (Tables 17 and 18). In fact, none of the experimental factors nor their interactions affected the maximum lateral distance traversed per deviation. The time outside the travel lane per deviation also was not affected by the presence of the rumbling treatments (Tables 19 and 20).

Countermeasure presence had an effect on the time between successive left-side departures. The main effect of Countermeasure approached significance ($p=.057$; Table 21) and reflected an overall increase of approximately one minute between deviations as shown in Figure 11. The BAC x Countermeasure interaction was significant, indicating different countermeasure effects at two or more BAC levels. As shown in Figure 11, this effect reflects increases similar to the overall effect for the two alcohol conditions (BAC2, BAC3) and a large decrease at the sober (BAC1) condition. Post hoc Scheffé tests were conducted on the three simple effects (i.e., countermeasure effect at each BAC level). The results were negative indicating no significant effect at any BAC level. The non-significance of the apparently large decrease in time associated with countermeasure presence in the sober (BAC1) condition reflects the small frequencies of deviations recorded in that condition.



NS : Not significant

FIGURE 10. - FREQUENCY OF LEFT LANE DEVIATIONS BY BAC AND COUNTERMEASURE PRESENCE (NON-RELIABLE EFFECT)



NS: Not significant

FIGURE 11. - TIME BETWEEN SUCCESSIVE LEFT-SIDE DEVIATIONS BY BAC AND COUNTERMEASURE PRESENCE

Countermeasure effectiveness was also examined using four measures of general driving performance (mean velocity, standard deviation of velocity, mean lateral position, standard deviation of lateral position). For mean velocity, the main effect of Countermeasure was significant on both the straight and curved road sections (Tables 23 and 24). As shown in Figure 12, countermeasure presence was associated with an overall speed increase of approximately .5 mph for the straight and 1.0 mph for the curved road. The BAC x Countermeasure interactions were significant for mean velocity on both road types. Scheffé post hoc analyses were conducted to examine the countermeasure effect at each of the BAC levels. On the straight road, the speed increase (1.8 mph) at BAC1 was statistically reliable. The effects at BAC1 (.9 mph increase) and BAC2 (.9 mph decrease) were not reliable. On the curved road, countermeasure presence was associated with larger effects. The speed increase (2.8 mph) at BAC3 was significant, as was the decrease (1.4 mph) at BAC2. The increase (1.3 mph) at BAC1 was not significant. The means for these two effects are shown in Figure 13.

Countermeasure presence had no overall effect on the transformed standard deviation of velocity, either on the straight or curved road segments (Tables 25 and 26). The BAC x Countermeasure effect was significant for the straight road data. Post hoc Scheffé tests were conducted to test the effects of countermeasure presence at each of the three levels of BAC. Although reductions were observed at the two alcohol conditions, neither was statistically reliable.

The mean lateral placement on the straight road segment was significantly affected by Countermeasure presence (Table 27). Examination of the cell means revealed that subjects moved closer to the centerline in the Countermeasure present condition. The mean distances of the test vehicle from the centerline in the absence and presence of the countermeasure were 1.90 and 1.75 feet, respectively. This effect was not apparent on the curved road segment (Table 28).

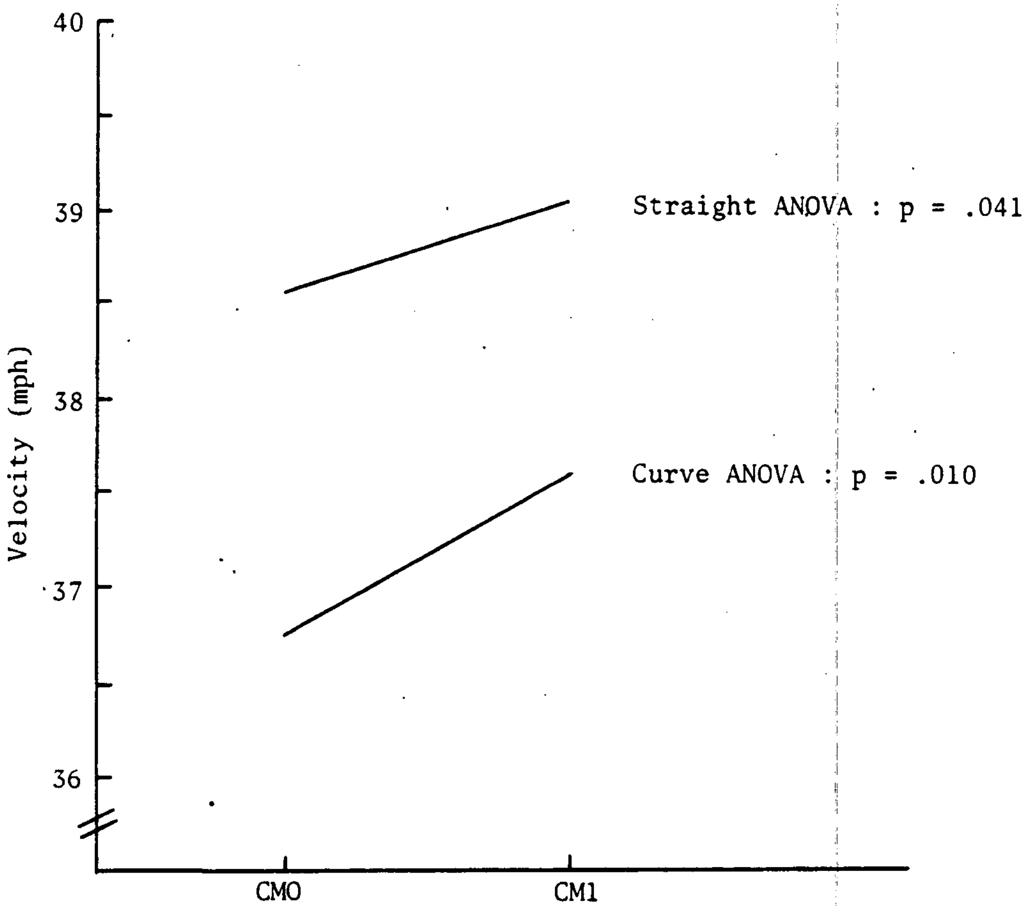
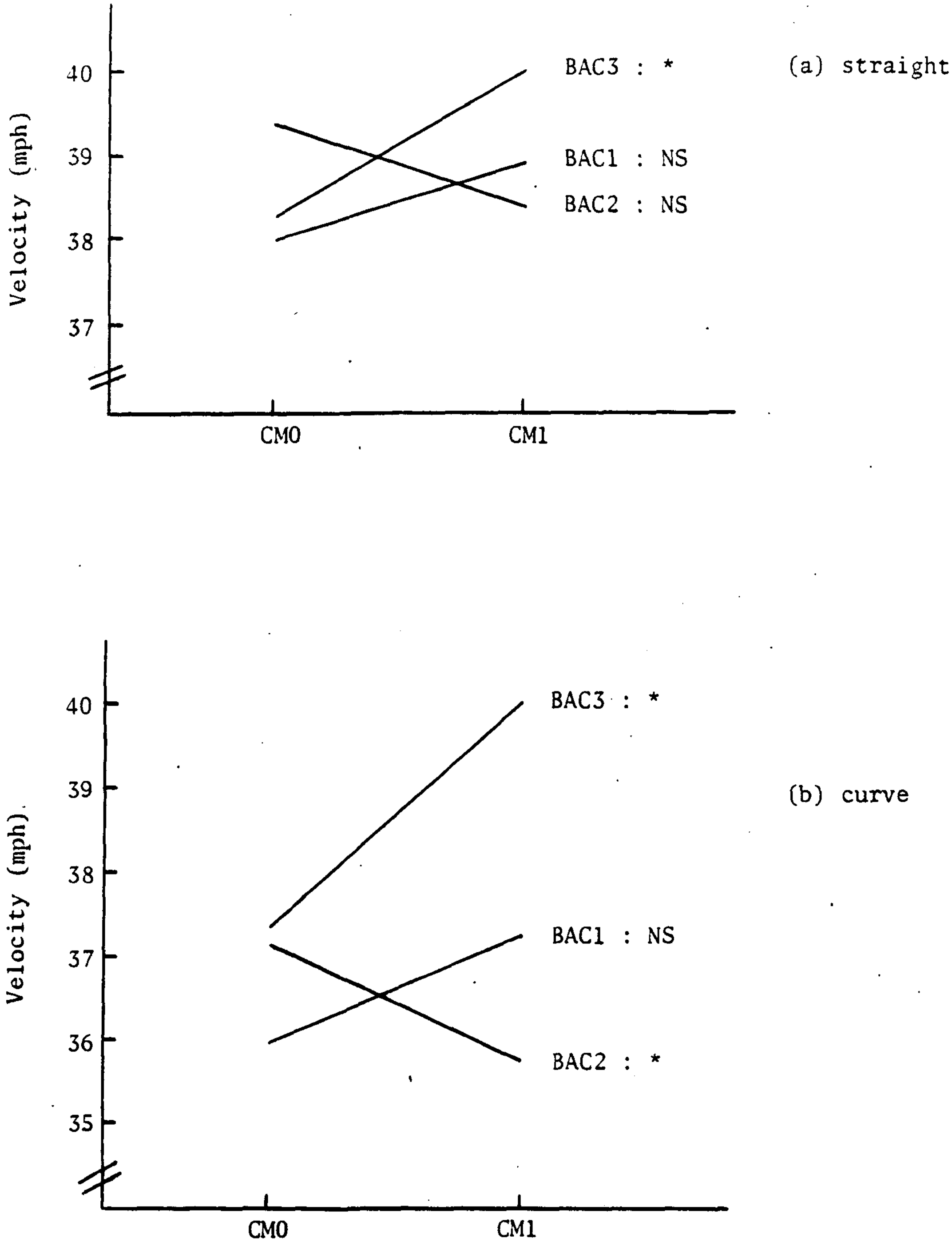


FIGURE 12. - MEAN VELOCITY ON STRAIGHT AND CURVED ROAD BY COUNTERMEASURE PRESENCE



* : Significant difference identified through post hoc analyses
NS : Not significant

FIGURE 13. - MEAN VELOCITY BY BAC AND COUNTERMEASURE PRESENCE ON STRAIGHT AND CURVED ROAD

The standard deviation of lateral position exhibited a significant overall reduction associated with countermeasure presence on the curved road (Table 30). The BAC x Countermeasure interaction was also significant, indicating different effects at the three BAC levels. Examination of the cell means revealed countermeasure-related reductions at the two alcohol conditions, and a slight increase at the sober condition. Post hoc analyses, however, revealed none of these simple effects to be significant. The data are shown in Figure 14.

For the straight road segment, the main effect of Countermeasure approached significance ($p = .081$; Table 29). Examination of the cell means revealed a slight reduction associated with countermeasure presence. The BAC x Countermeasure interaction was not statistically reliable.

The effects of the treatment presence are summarized in Table 34. The magnitudes of the effects are presented in Table 35. Please note that unlike the two tables summarizing alcohol effects (Tables 32 and 33), this table includes a number of statistically non-reliable effects. Furthermore, as indicated, post hoc analyses on reliable BAC x Countermeasure interaction effects in several cases revealed non-reliable simple effects. In this situation, it must be concluded that the effect of Countermeasure presence differed significantly among the different BAC levels, but that when each level was examined separately, none of the effects was strong enough to attain statistical significance. The significance of the BAC x Countermeasure interaction was the basis for inclusion in the table.

Effects of Time Segment. Each experimental session was divided into four thirty-minute segments. Direction of travel on the test course was alternated by segment, such that in Segments 1 and 3 the direction of travel was clockwise and in Segments 2 and 4 the direction of travel was counterclockwise. It was hypothesized that over the two hour experimental drive, performance would degrade, reflecting a fatigue effect. Main effects of Segment (SEG) in the ANOVAs were interpreted to reflect this effect. Interactions of Segment with BAC and Countermeasure were also of interest in determining how time affected subjects at different BAC levels and how countermeasure effectiveness changed over time.

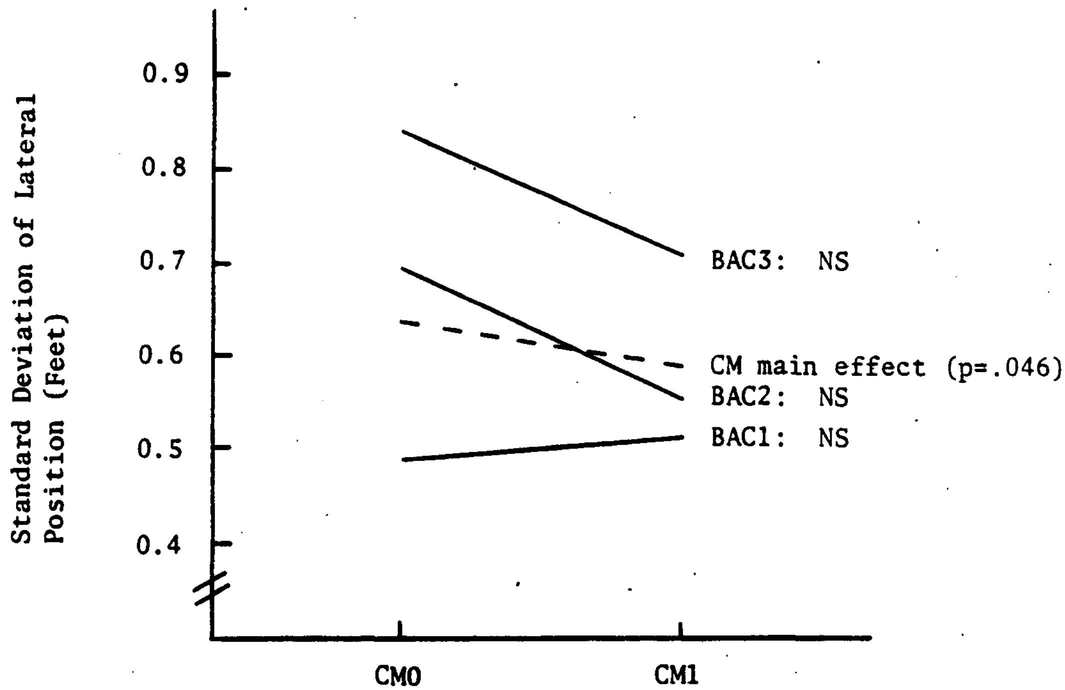


FIGURE 14. - STANDARD DEVIATION OF LATERAL POSITION BY BAC AND COUNTERMEASURE PRESENCE (CURVED ROAD)

TABLE 34. - SUMMARY OF COUNTERMEASURE EFFECTS

Measure	Data Subset	Countermeasure Effect[1]	Interpretation[2]
Deviation frequency	Left	No	Nonsignificant decrease at high BAC
	Right	No	
Lateral distance off road	Left	No	
	Right	No	
Time between deviations	Left	Yes	Nonsignificant overall increase ($p < .06$) Nonsignficant increase at high BAC condition
	Right	No	
Mean velocity	Curve	Yes	Significant overall increase Significant increase at BAC3 Significant decrease at BAC2
	Straight	Yes	Significant overall increase Significant increase at BAC3
Standard deviation of velocity	Curve	No	
	Straight	No	
Mean Lateral position	Curve	No	
	Straight	Yes	Significant movement toward centerline
Standard deviation of lateral position	Curve	Yes	Significant overall reduction Nonsignificant reductions at BAC2 and BAC3
	Straight	No	Nonsignificant ($p < .08$) overall decrease

[1]Yes indicates significant main effect or BAC x CM interaction.
[2]Effects refer to the presence versus absence of the countermeasure treatments. Overall effect refers to countermeasure main effect. Effects at individual BAC levels refer to simple effects tested if BAC x Countermeasure interaction was significant.

TABLE 35. - MAGNITUDE OF COUNTERMEASURE EFFECTS[1]

Measure	BAC Level[2]	CM0	CM1	Diff.	% Change	Units	Interpretation
Left deviation frequency	BAC3	6.34	3.48	-2.86	-45	Deviations per 30 minute segment	Nonsignificant main effect (p=.091)
Time between successive deviations: Left	All	163.16	221.13	57.97	36	Seconds	Main effect approached significance (p=.057)
	BAC1	768.46	196.51	-571.95	-74		BAC x CM interaction significant
	BAC2	348.03	410.90	62.87	18		Simple effects not significant
	BAC3	114.73	181.80	67.07	58		
Mean velocity:							
Straight	All	36.73	37.61	.88		mph	Significant main effect
	BAC3	38.24	40.05	1.81	5		Significant simple effect at BAC3.
Curve	All	36.73	37.61	.88	2		Significant main effect
	BAC2	37.13	35.75	-1.38	-4		Significant simple effect at BAC2 and BAC3
	BAC3	37.30	40.05	2.75	7		
Standard deviation of velocity: straight	BAC2	0.95	0.89	-0.06	-6	mph	BAC x CM interaction significant
	BAC3	1.36	1.16	-0.20	-15		Simple effects not significant
Mean lateral position: straight	All	1.90	1.75	-0.15	-8	Feet from centerline	Significant main effect
Standard deviation of lateral position:							
Straight	All	0.51	0.50	-0.01	-2	Feet	Main effect approached significance (p=.081)
Curve	All	0.64	0.59	-0.05	-8		Significant main effect
	BAC1	0.69	0.56	-0.13	-19		BAC x CM interaction significant
	BAC2	0.84	0.72	-0.12	-14		Simple effects not significant
	BAC3	0.49	0.52	0.03	6		

[1]Includes non-reliable effects.

[2]All levels indicates countermeasure main effect. BAC1, BAC2, BAC3 are simple effects which were tested if BAC x Countermeasure interaction was significant.

The frequency of left side lane deviations was not affected by SEG (Table 12). Right side lane deviation frequency, however, did increase significantly with SEG (Table 13). Although Scheffé post hoc analyses revealed no reliable differences, the largest difference between consecutive segments was observed between the first and second time segments. A small increase was found between the second and third segment. The maximum frequency occurred during the third segment. The mean frequency at the fourth segment was identical to that of the second segment. These data are shown in Figure 15.

The maximum distance off the road per deviation was not affected by SEG. This was true for both left and right deviations (Tables 17 and 18).

The time per deviation outside the travel lane for left side departures increased with SEG, but not significantly ($p=.093$; Table 19). For right side departures the main effect of segment was not significant. Although the SEG x BAC and SEG x BAC x CM interactions were significant, the data were not readily interpretable.

The time between successive left side deviations increased with SEG, although again the effect was not significant ($p=.071$; Table 21). The BAC x SEG interaction for this measure, however, was significant ($p=.050$). Examination of the means revealed an increase in the time between successive left side deviations for the sober and low BAC conditions with time, but no effect at the high BAC condition (see Figure 16). The effect was most apparent at the low BAC condition, where in the third segment the time between successive deviations was longest. Post hoc Scheffé tests conducted on the simple effects of SEG at each of the three BAC levels revealed no reliable differences.

The time between successive right side deviations revealed no effects of time segment (Table 22).

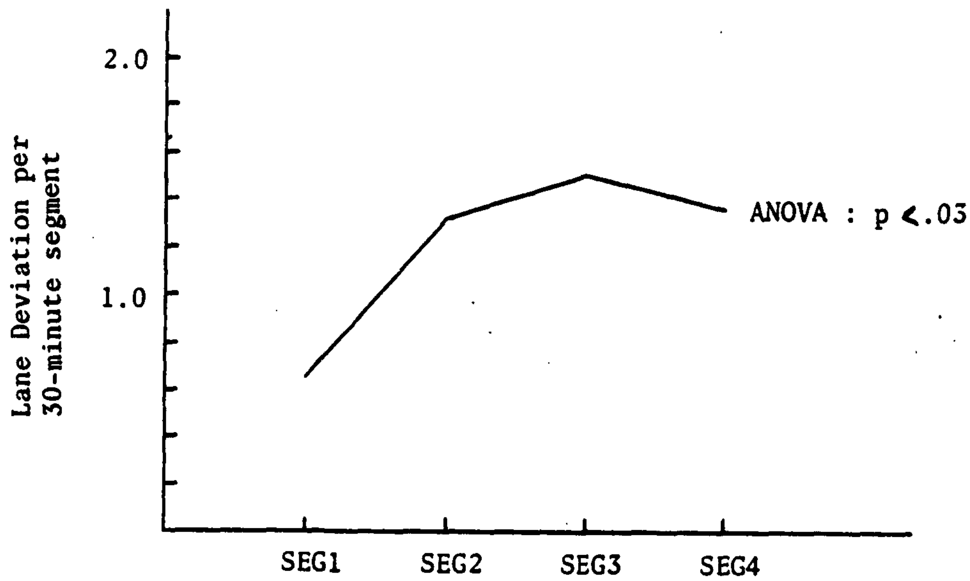
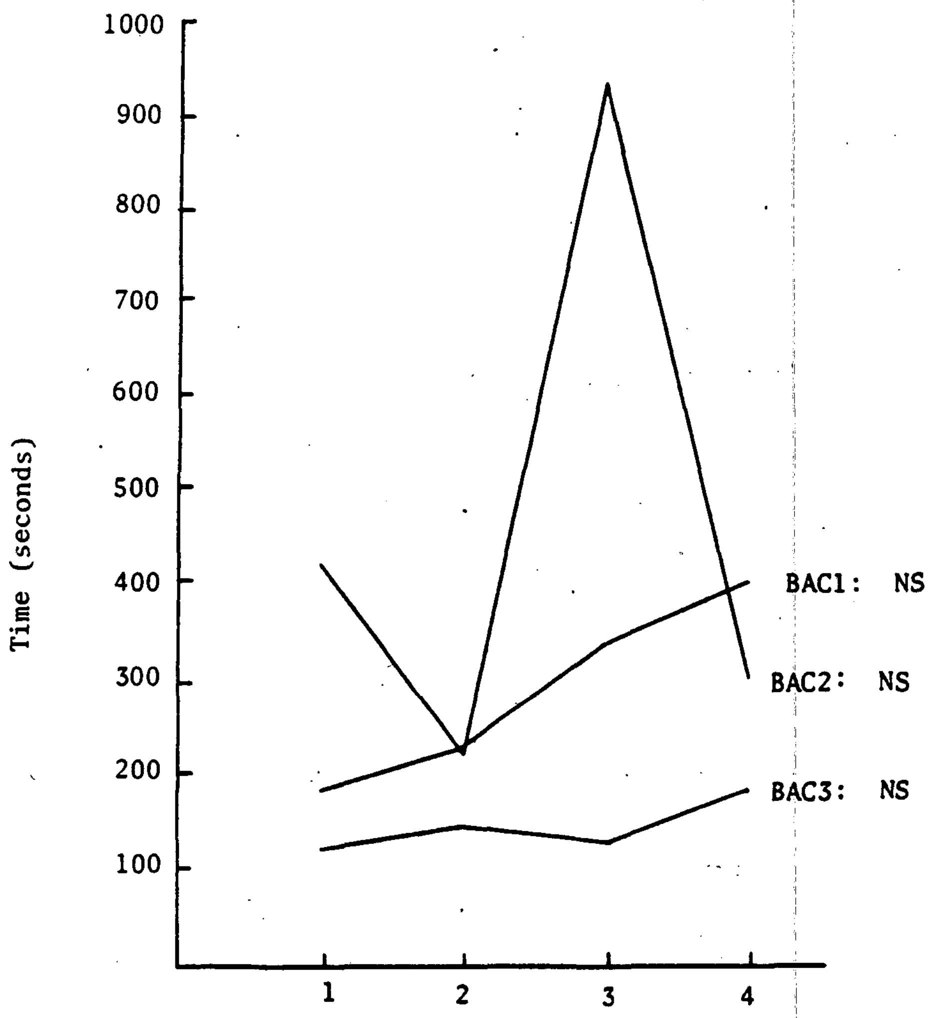


FIGURE 15. - RIGHT LANE DEVIATION FREQUENCY BY TIME SEGMENT

Several measures of driving performance also exhibited reliable effects of time segment. The main effect of SEG on straight road velocity was significant (Table 23). Post hoc analyses on the means revealed the effect to be associated with the fourth thirty-minute segment (SEG4). All other means were found different from SEG4, while SEG1, SEG2 and SEG3 were found not different from each other. The means are shown in Figure 17. The BAC x SEG interaction for this measure was not significant (Table 23), indicating a uniform time effect across BAC levels.

The main effect of SEG on curved road mean velocity was not significant (Table 24). The BAC x SEG interaction, however, was reliable indicating different time-related performance changes according to BAC level. Post hoc Scheffé analyses revealed the effect to be associated with the sober (BAC1)



NS: Not Significant

FIGURE 16. - TIME BETWEEN SUCCESSIVE LEFT-SIDE DEVIATIONS BY BAC AND SEGMENT

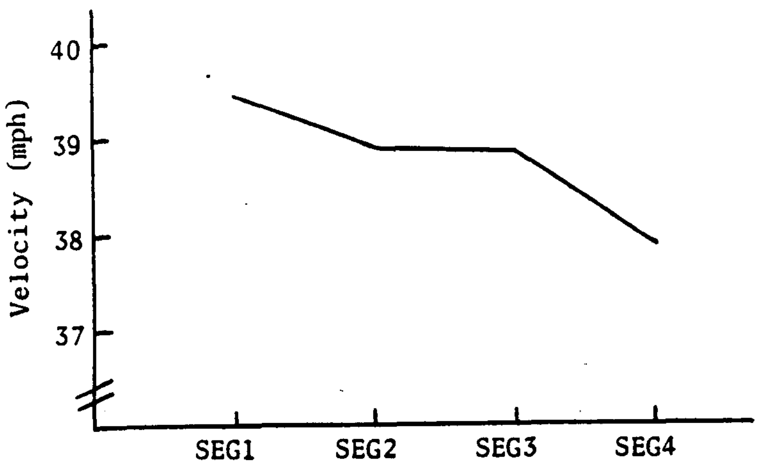
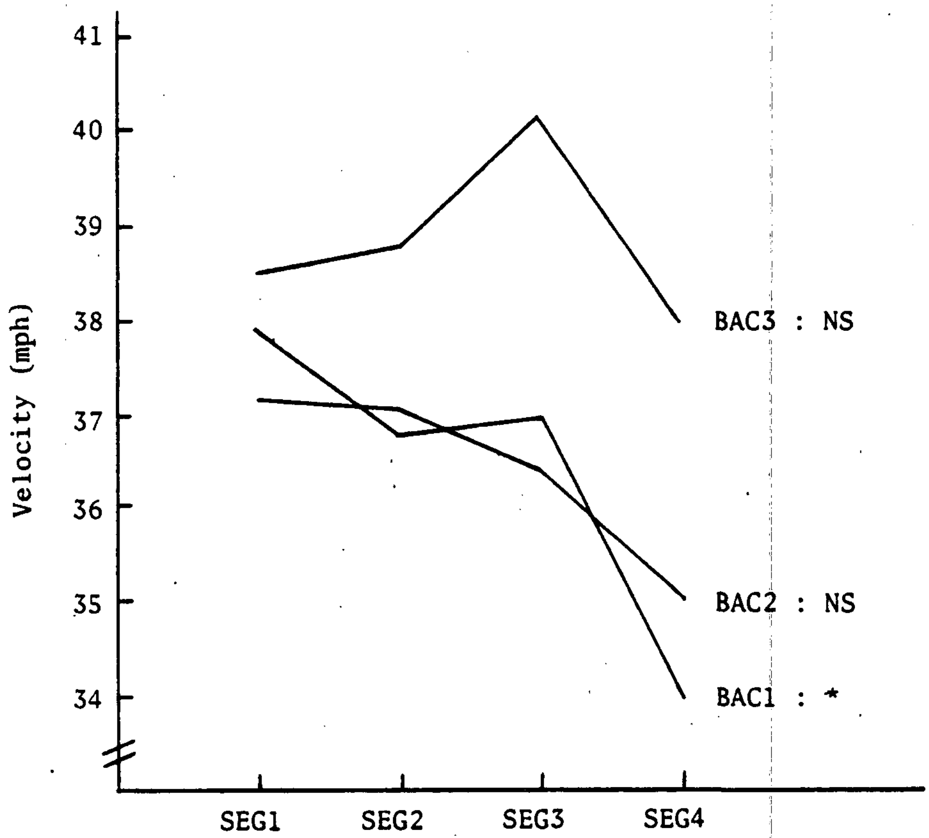


FIGURE 17. - MEAN VELOCITY ON THE STRAIGHT ROAD
BY TIME SEGMENT

condition. In this condition, the mean velocity at SEG4 was significantly slower than those associated with SEG1, SEG2 and SEG3. As shown in Figure 18, a similar, although non-significant, effect is evident at BAC2. Drivers in the high BAC (BAC3) condition were least likely to have reduced speed over time on the curved road.

The Countermeasure x SEG interactions for both straight and curved road mean velocity were statistically significant, indicating changes in countermeasure effects over time. The means for both effects are shown in Figure 19. Scheffé post hoc analyses on the straight road data indicated a time-related velocity reduction (SEG1 vs SEG4) in the presence of the countermeasure (CM1). In the absence of the countermeasure (CM0), the velocity change was not significant over time.

The magnitudes of the effects were greater for the curved road. In the absence of the countermeasure (CM0), a time-related speed reduction (SEG1 vs SEG4 and SEG2 vs SEG4) was identified through post hoc analyses. Countermeasure presence was associated with faster speeds in SEG1 and SEG3, but

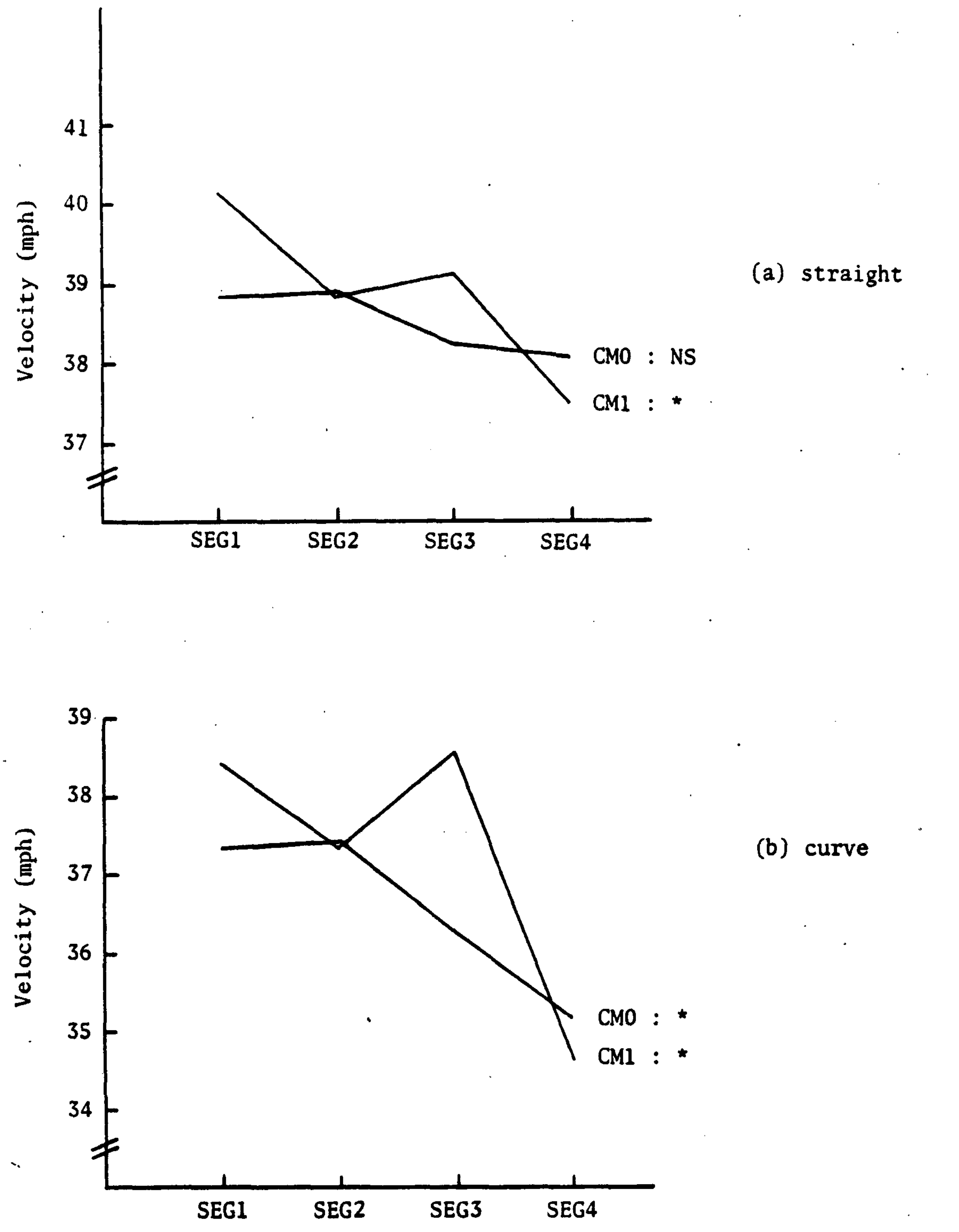


* : Significant difference identified through post hoc analyses
NS : Not significant

FIGURE 18. - MEAN VELOCITY BY BAC AND TIME SEGMENT
(CURVED ROAD)

not in SEG2 and SEG4. The fact that countermeasure presence affected both straight and curved road speeds primarily in SEG1 and SEG3, indicates a possible effect of travel direction.

The standard deviation of velocity on the curved road exhibited a significant main effect of Segment (Table 26). Examination of the means revealed that the effect reflected a significant increase in the fourth (last) 30-minute segment over the means of the first and third. However, the fact that the mean for the fourth segment was not significantly different from the mean for the second segment, indicates the effect may be reflecting differences associated with travel direction on the course. The effect on the curved road was not significant.



* : Significant difference identified through post hoc analyses
NS : Not significant

FIGURE 19. - MEAN VELOCITY BY TIME SEGMENT AND COUNTERMEASURE PRESENCE

For lateral position on both the straight and curved road sections, the significant main effects of SEG (Tables 27 and 28) reflect differences attributable to direction of travel on the test track. This is revealed by the post hoc analyses which indicated differences between successive segment means (different travel directions), but not between SEG1 and SEG3 or SEG2 and SEG4, where travel direction was the same. The significant interactions with SEG also reflect differences attributable to travel direction.

Lateral position variance on the straight road segment (standard deviation of lateral position) exhibited a significant main effect of SEG and a significant BAC x SEG interaction (Table 29). Both effects were strongly influenced by effects of travel direction, however the interaction revealed a time-related decrease in lateral position variability in the sober condition (BAC1), as contrasted with a time-related increase at the two alcohol conditions (BAC2 and BAC3). Post hoc analyses on the main effect revealed significant differences between the following segment pairs: 1-4, 2-3, 3-4. Post hoc analyses on the time effects at the three BAC levels, revealed no significant differences. The data are shown in Figure 20.

The effects of Time Segment are summarized in Table 36.

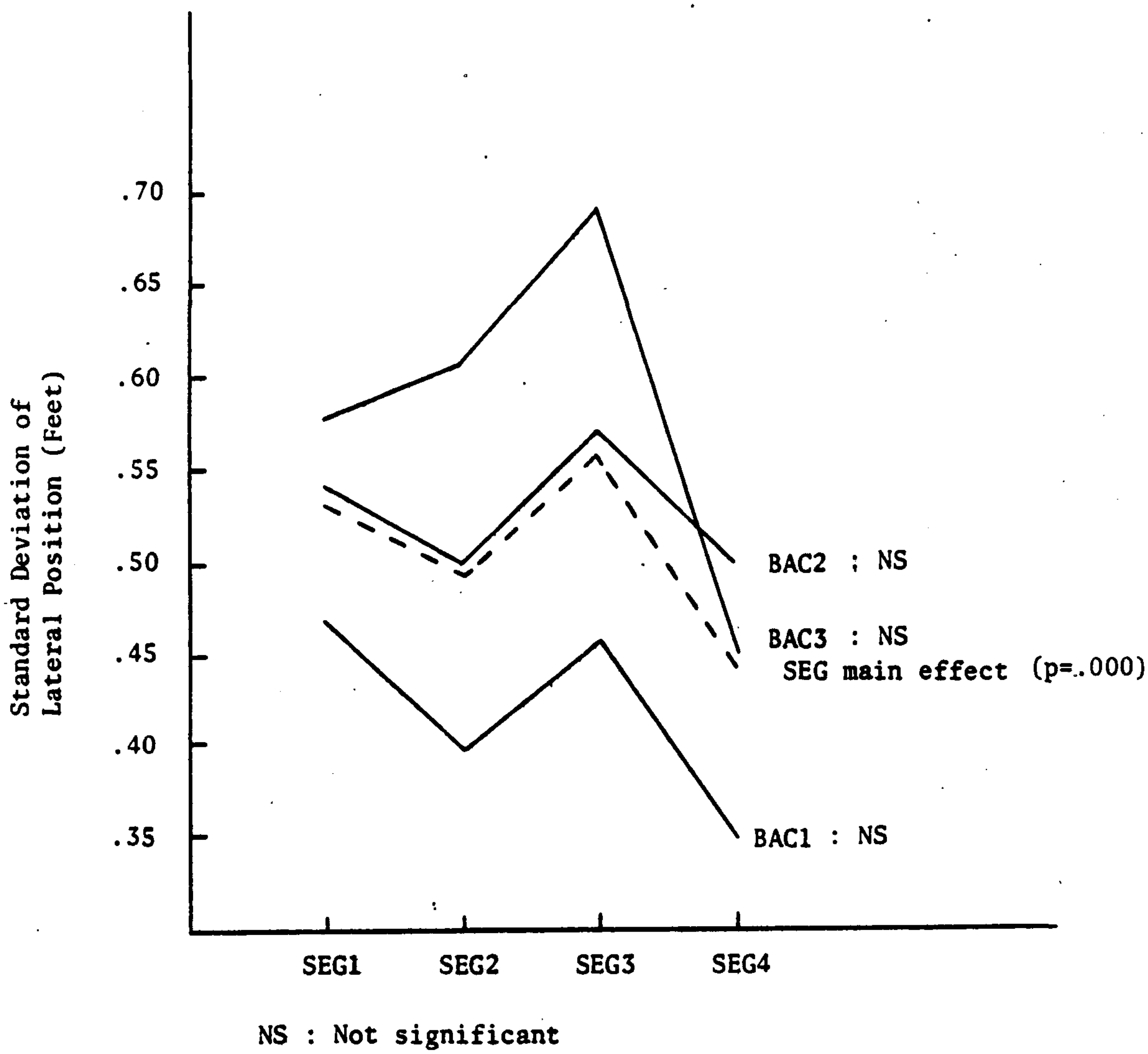


FIGURE 20. - STANDARD DEVIATION OF LATERAL POSITION BY BAC AND TIME SEGMENT (STRAIGHT ROAD)

TABLE 36. - SUMMARY OF TIME SEGMENT EFFECTS

Measure	Time Segment Effect[1]	Interpretation
Lane deviation frequency		
left	No	
right	Yes	increases between SEG1, SEG2 and SEG3
Maximum lateral distance off road:		
left	No	
right	No	
Time off road:		
left	No	nonsignificant overall increase (p=.09)
right	No	
Time between deviations:		
left	Yes	nonsignificant overall increase (p=.07)
right	No	
Mean velocity:		
straight	Yes	significant overall decrease
curve	Yes	significant decrease at BAC1
Standard deviation of velocity:		
straight	No	
curve	Yes	significant overall increase
Mean lateral position:		
straight	Yes	differences attributable to direction of travel
curve	Yes	differences attributable to direction of travel
Standard deviation of lateral position:		
straight	Yes	significant decrease at BAC1
curve	No	

[1]Yes indicates significant main effect or BACxSEG interaction

4.2 Experiment II - Simulator Study of Selected Roadway Treatments

Based upon the results of the preliminary evaluation presented in Section 3 of this report, and upon the priorities of NHTSA and FHWA, roadway treatments were selected for experimental evaluation. The three categories of treatments selected include:

(1) Roadway delineation - With the objective of providing continuous guidance information to indicate roadway alignment, especially under nighttime driving conditions, delineation treatments include:

- edgelines
  - standard (4 inches)
  - wide (8 inches)
- post delineators

(2) Hazard warning devices - For emphasizing specific hazardous locations (which for drinking drivers includes curves, particularly sharp isolated curves on rural two-lane roads) potential warning devices include:

- active (flashing) displays
- chevron alignment signs

(3) Patterned pavement markings - Specific patterns are intended to create illusions of increased speed, increased curvature, or a narrowing of the travel lane.

4.2.1 Previous Research

The selected countermeasures differ regarding the amount of previous research (including accident and experimental studies) conducted to determine their effectiveness. With the exception of one experimental study (Nedas, et al., 1981), none of the studies has considered the potential benefit of roadway treatments to alcohol-impaired drivers. Therefore, unless otherwise indicated, the research described below pertains to the overall effectiveness of the roadway devices, without specific consideration of alcohol-impaired drivers.

(1) Pavement edgelines. Although used extensively throughout the country, delineation treatments have been difficult to justify through analyses of accident data. In a recent study which combined data from ten states, Bali, et al. (1978) reported difficulty in selecting accidents related to delineation presence and in controlling for treatment condition (e.g., newly painted, worn, etc.), which can vary considerably. Cautioning that observed statistical relationships were not strong enough to interpret the findings as conclusive, the authors reported mixed results for the presence versus absence of edgelines. Whereas significant positive effects were found on all general (tangent plus winding) and tangent road segments, negative effects were found on winding sites and on horizontal curves in the Federal Aid primary system.

Stimpson, et al. (1977) evaluated a number of different delineation treatments and concluded that "sufficient national experience has accumulated to warrant the use of edgelines, at least narrow ones, on all pavement widths of 20 feet or greater." Bali, et al. (1976) reported the results of two relevant observational studies. In the first, edgeline presence was found to positively affect speed and lateral placement on two one-mile sections of rural roads which differed in the width of the roadway. Vehicles moved closer to the centerline at night, but were unaffected during the day. Speed results were mixed: mean speeds were lower on the 24 foot section, but higher for the 18 foot section. In the second study, edgeline presence was found to reduce speeds and the incidence of centerline straddling on curves.

Nedas, et al. (1981) summarized results from twelve studies which report positive effects of road markings in terms of accident, injury, and fatality reduction. Johnston (1981), however, suggested that existing accident studies are "typically unsatisfactory methodologically," and reviewed results of experimental studies which utilized indirect measures (primarily lateral position and speed) to evaluate delineation treatments. He reported a consistent finding that edgeline presence was associated with reduced lateral position variance, while the influence on speed was unclear. The results of a laboratory study where subjects were required to make judgments of curve direction, after viewing slides of rural curves taken at night, revealed that guide posts, but not edgelines, were effective in indicating curve direction.

Edgelines as an Alcohol Countermeasure - In a recent experimental study (Nedas, et al., 1981), alcohol-dosed subjects (BAC=.05 to.08%) drove at night on a closed section of two-lane roads. The approximately 10-mile course included fourteen 2000-feet segments, on which the different delineation treatments (standard, 4-inch, or wide, 6 and 8 inch, edgelines) were applied. Ten of the segments were curves, four were tangents*. Lateral position data were collected photographically at 20 points in each segment. The results indicated that edgeline presence:

a. decreased the range of lateral position (amount of road used),

b. reduced lateral position variability, and

c. affected mean vehicle position (drivers moved closer to the centerline).

Effects were reported for both sober and alcohol-dosed subjects. Although not statistically reliable, the presence of 8-inch edgelines was associated with further reductions in the first two measures (a and b, above). Results for the 6-inch edgelines were not consistent. Overall it was found that the dosed subjects

*Tangent sections were omitted from the analysis.

performed as well in the wide edgeline sections as the undosed subjects did in the standard edgeline sections. One potential problem with the design is that it was impossible to control for differences in lateral position variability due to differences in curve geometrics or in the type and nature of preview information associated with each curve, since each curve was implemented with only one treatment. However, the consistent effects do indicate the potential usefulness of such information in improving the tracking performance of alcohol-impaired drivers under nighttime conditions.

In the current study, driver performance was compared on both straight and curves road sections with standard, wide, or no edgelines. The use of the driving simulator allowed implementation of the different edgeline conditions on roads with identical geometrics, such that any observed differences are attributable to the edgeline condition and not to an interaction between the edgeline condition and road alignment.

(2) Post delineators - According to the MUTCD, post delineators are light-retroreflecting devices mounted at the side of the roadway, in series, to indicate the roadway alignment. They may be used on long continuous sections of highway or through short stretches where the alignment changes might be confusing. An advantage of post delineators is that they remain visible in conditions when pavement markings may be covered (e.g., snow or dirt).

Several research studies have evaluated the effectiveness of both standard MUTCD and non-standard applications of post delineators. One study (David, 1972), examined the effects of six patterns of post delineators on nighttime vehicle speed and lateral placement on a two-lane rural horizontal curve. It was found that driver performance (speed and lateral placement) was not affected solely by the presence or absence of any pattern of post delineators. Bali, et al. (1978), in their analysis of data from ten states, reported positive effects, in terms of accident rate reductions, for post delineators on tangent or winding road segments (in the presence or absence of edgelines). For isolated horizontal curves, indications were less clear; however, post delineators did reveal some positive effect in lowered accident rates.

Rockwell and Hungerford (1979) evaluated standard MUTCD and non-standard patterns of post delineators on horizontal curve negotiation using laboratory and field observational techniques. It was found that standard delineators positively affected vehicle approach speeds, curve negotiation speeds, and lateral placement of the vehicle during curve negotiation. They were particularly effective on sharp rural curves. The non-standard treatment was an ascending in/out pattern that created an illusion that the curve was sharper and closer than the same curve when the standard treatment was used. This treatment was associated with a significant reduction in vehicle speed between the approach and negotiation of the curve. For both treatments the long term effects were significantly less than the immediate effects, which suggested that the benefit of such devices would be greatest for transient rather than local drivers (Rockwell and Hungerford, 1979).

For the current study, post delineators were implemented on curves only. Measures of driver performance were recorded to determine how post delineators compare to standard and wide edgelines, as well as to other spot treatments on curves.

(3) Hazard warning signs - Hazard identification beacons are used to supplement appropriate warning or regulatory signs. Their potential as an alcohol countermeasure derives from their exaggerated conspicuity which may counteract the slowed reaction time and lapses of attention characteristic of alcohol-impaired driving. This is especially important at unexpected hazardous locations, where preview is restricted. Flashing beacons have been evaluated in a number of different applications including in conjunction with speed reduction signing (Brackett, 1964), in school zones (Brackett, 1965), on curves with high skid potential (Hanscom, 1974), on approaches to potentially icy bridges (Kobett, Glauz and Balmer, 1972), in work zones (Lyles, 1981), and at railroad grade crossings (Morrissey, 1980). Effectiveness is generally measured

in terms of speed reductions. Where reductions do occur, they typically involve the vehicles traveling at higher speeds (c.f., Hanscom, 1974; Kobett, et al., 1972).

In several of these studies, both speed and interview data were available, so that correlations between speed reduction and drivers' reported awareness of the sign could be obtained. The results of these studies indicate that the relationships between driver awareness of the existence of the sign, ability to recall its message, and reduction of speed, are not clear-cut. In one study (Kobett, et al., 1972), it was reported that some drivers saw but did not read the sign, and of these drivers, some slowed down while others did not.

In this study, flashing beacons were used to supplement curve warning signs. Their effect on speed in the approach to different curve types was examined for subjects when sober and alcohol-dosed.

(4) Patterned pavement markings - In addition to more traditional road markings, two studies (Denton, 1973; Shinar, et al., 1980) have examined the effects of various innovative patterns painted along the approaches to curves or other hazards. In both studies, transverse stripes were painted across the road at successively decreasing intervals to give the illusion of increased speed to approaching drivers. Shinar, et al. (1980) also used a Wundt illusion, painted along the approach to a short sharp curve with restricted preview. The Wundt illusion, which indicates an apparent narrowing of the roadway, was hypothesized "to alert the driver to the need for careful lateral control" in the approach and negotiation of the curve.

Both treatments were effective in reducing speeds, although at different points in the curve approach. The major effect for the transverse striping was at the 'perceptual' end of the striping, as might be expected. The Wundt illusion had an effect at the beginning of the curve. Both perceptual countermeasures were associated with greater speed reductions than a warning sign with a novel message ('Deceptive Curve'). These results are consistent with findings that proportionately more direct foveal following of the alignment is typical during negotiation of curves than of straight roads (Shinar, et al., 1977), thus reducing the likelihood of a sign being noticed or responded to.

A herringbone pattern of transverse striping which resembles the Wundt illusion was used in the current study. The pattern was implemented throughout the transition and fixed part of different curve types to evaluate its effect on speed, lateral position and lateral acceleration.

4.2.2 Purpose of Study

The objectives of the simulator study described herein were:

1) To determine if providing enhanced visual information concerning the roadway alignment improves the performance of selected drivers when sober and alcohol-impaired,

2) To determine if the effects of selected roadway countermeasures vary with the demands of the driving task,

3) To determine if the countermeasure effects change over time, and

4) To determine if the countermeasure effects differ by road alignment (straight versus curved sections).

4.2.3 Methodology

Design

A within-subjects design was used to evaluate the effectiveness of the selected countermeasures on driving behavior at different BACs, attentional demand states, and types of curve. The main between-session design factors are presented schematically in Figure 21.

Attentional Demand	0.00%	0.07%	0.12%
Uneventful			
Eventful			

Target BAC

FIGURE 21. - BETWEEN SESSION EXPERIMENTAL DESIGN

The target BACs (0.00, 0.07, 0.12%) were selected to be consistent with the closed course experiment, and to ensure that subjects remained above or near the .05 and .10% levels, during each respective two-hour session.

Two levels of attentional demand were used. The uneventful condition simulated a nighttime drive on a rural two-lane roadway. The frequency of events requiring response (i.e., curves, signs) corresponded roughly to the task demands of the closed course experiment. The eventful condition simulated a suburban two-lane roadway, and required responses to unexpected obstacles in addition to curves and signs. Both scenarios required subjects to drive continuously for two hours. The scenarios are described in greater detail in the Driving Task section.

The within-session experimental design is presented in Figure 22. This within-session block corresponds to a single one-hour block of the driving scenario timeline (Figure 23). Each edgeline layer of Figure 22 corresponds to a 20-minute segment in Figure 23. During each 20-minute segment of a two-hour drive, the edgeline condition remained constant. All 25 curve type x spot treatment combinations occurred within each 20-minute segment. Therefore, during each two-hour drive, a subject drove six 20-minute segments, including two with each edgeline type. Because curve type and spot treatment varied within 20-minute segments, the subject negotiated 150 (6 segments x 5 curve types x 5 spot treatments) curves during the two hours. An approximately equal number of left and right curves were included within each drive.

The five curve types were selected to provide a wide spectrum of tracking demands, and to be consistent with the curves on the closed course. Differences in the handling characteristics of the simulator and instrumented vehicle, however, precluded a direct matching of the curve characteristics. Curve descriptions are presented in Table 37.

TABLE 37. - CURVE DESCRIPTIONS

Curve No.	Radius of Curvature	Heading Change	Advisory Speed (mph)	Critical* Speed (mph)	Total Length of Curve
1	188 ft.	90	20	39	495 ft.
2	188 ft.	60	30	39	436 ft.
3	265.8 ft.	45/45**	35	47	410 ft.
4	309.2 ft.	135	40	50	1,030 ft.
5	356 ft.	90	45	54	860 ft.

*Tire limit set @ .55 g's. (When lateral acceleration exceeds tire limit, loss of control is probable.)

**S-shaped curve

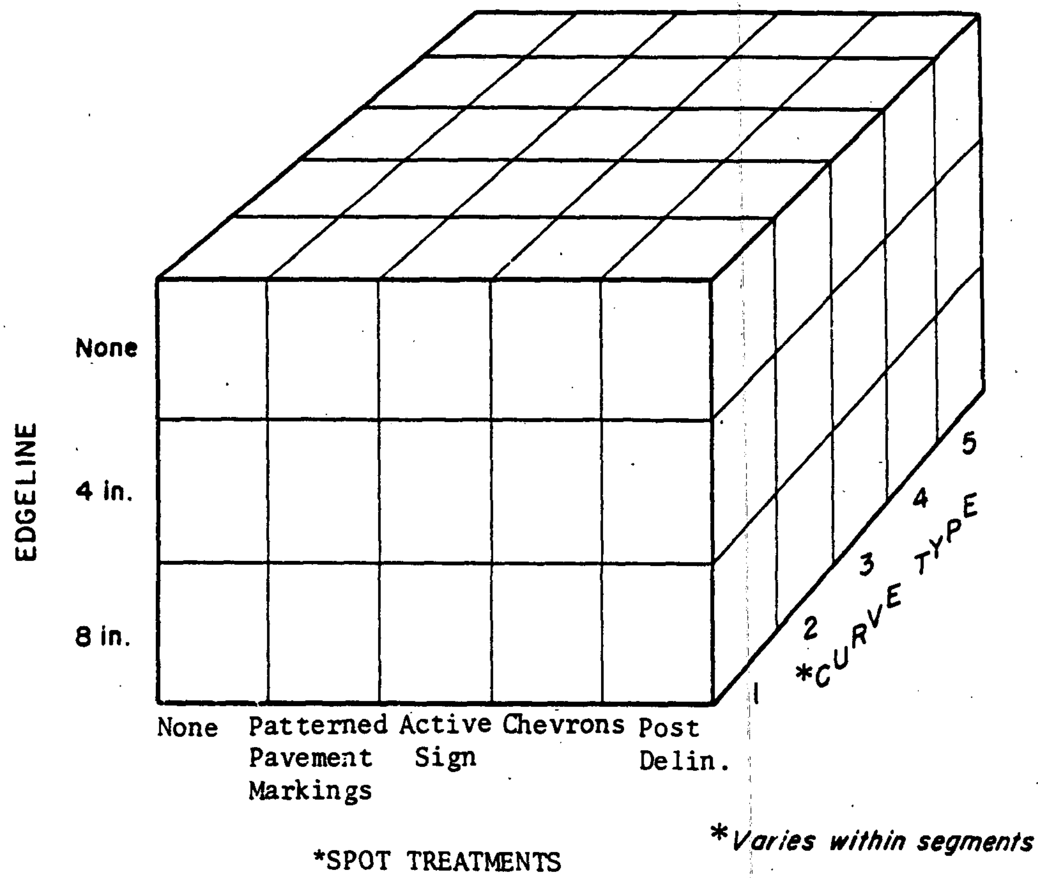


FIGURE 22. - WITHIN SESSION EXPERIMENTAL DESIGN

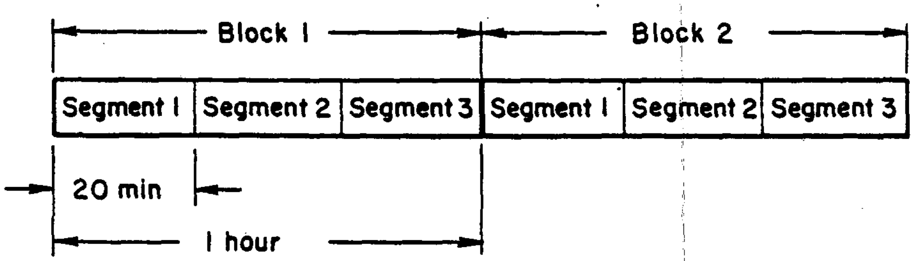


FIGURE 23. - DRIVING SCENARIO TIMELINE

Treatments

Each subject completed six experimental sessions (3 BAC levels x 2 levels of attentional demand; see Figure 21). Treatment order was counterbalanced across BAC level and level of attentional demand to distribute order effects equally over all cells.

Apparatus

The STI simulator is a completely instrumented cab resting on a fixed base. A functional description of the driving simulator is illustrated in Figure 24. Control signals from the car cab (i.e., steering, accelerator, and brake) are fed to automobile equations of motion which are mechanized on an analog computer (EAI231R). These equations then drive the cab instruments and interactive display generator which presents road delineation cues via a CRT display. For this study, the display's motion dynamics were programmed to simulate a Honda Accord with automatic transmission and power steering/brakes. The simulator is located in a quiet darkened room set apart from the experimenter's station by a curtain.

The road display observed by the driver consists of three components. The CRT image is optically combined with two slide-projected images through a combining glass as shown in Figure 24. One slide image consists of a sign projected through a zoom lens which is controlled to simulate apparent increasing sign size as the driver approaches the sign. The other image is a fixed size horizon scene which provides a visual texture background for the sign images. Both the sign and horizon images are horizontally deflected by a servo-controlled mirror which is moved proportionately to vehicle heading

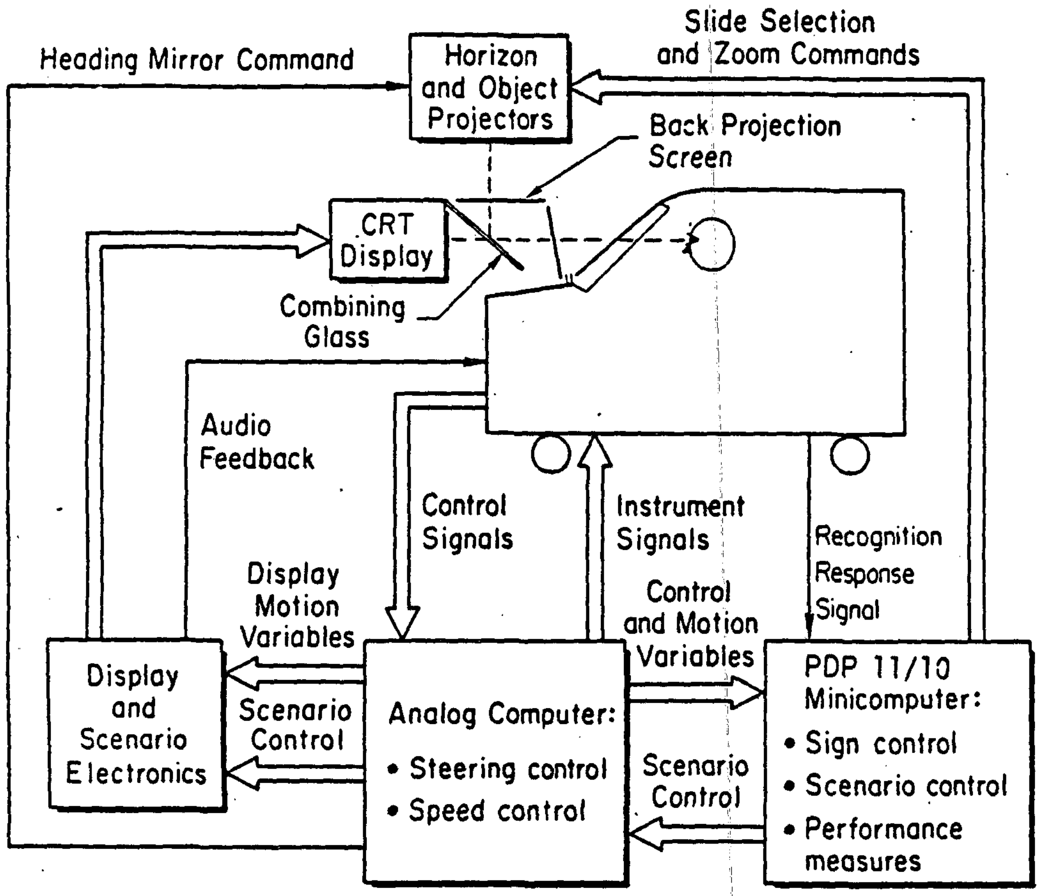


FIGURE 24. - FUNCTIONAL BLOCK DIAGRAM OF DRIVING SIMULATOR

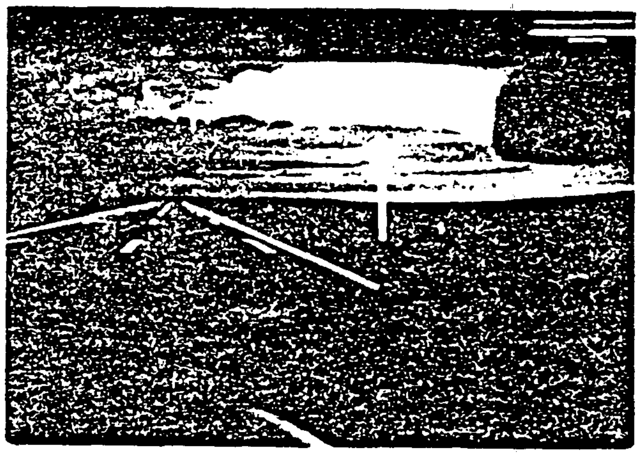
consistent with the CRT delineation image. The resulting roadway display image viewed by the driver is shown in Figure 25. A Fresnel lens has been mounted in front of the CRT display in order to provide modest magnification (~1.5X) and also to collimate the road image to create the illusion of distance.

The driving scenario or sequence of events encountered by the driver was controlled by a digital minicomputer (PDP 11/10) as shown in Figure 24. The computer controlled road curvature, placement of "police" for detecting speeding violations [55 mph (88 km/h) speed limit], and sign presentation. The sign slides were presented with a random access projector controlled by the minicomputer. The scenario event sequences were stored in the minicomputer and are called up from a keyboard at the beginning of a run.

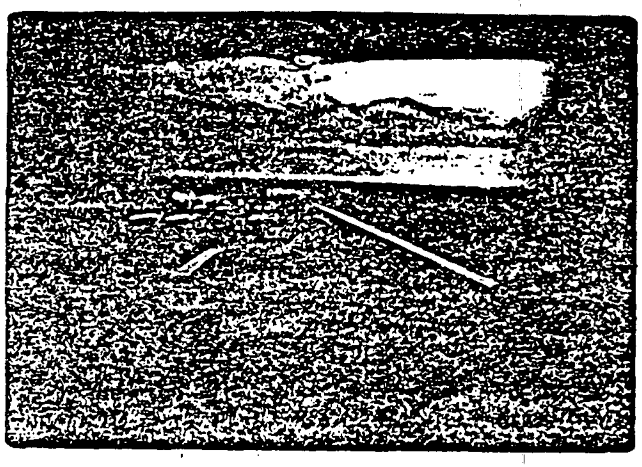
The minicomputer controlled the sign projector lens zoom ratio based on distance from the sign in order to achieve proper apparent sign size. The minicomputer also automatically computed performance measures and stored data on floppy disks. The experimental data base was subsequently transferred to the AMDAHL 470v/8B computer at Texas A&M University where statistical analyses were performed.

Countermeasure Specifications

As indicated above, the continuous treatments consisted of either no, standard (4-inch) or wide (8-inch) edgelines. Edgeline condition was constant for each 20 minute segment of the driving scenario (see Figure 23). Spot countermeasure treatments were implemented on curves only and followed the specifications of the Manual on Uniform Traffic Control Devices (MUTCD, 1978) where applicable. Specific implementation for each spot treatment is described below.



a) Roadsign Foreground Image

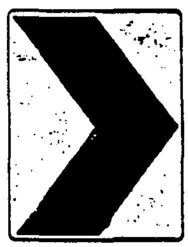


b) Opposing Traffic Foreground Image

FIGURE 25. - CAR SIMULATOR DISPLAY SHOWING CRT-DRAWN ROADWAY DELINEATION OPTICALLY COMBINED WITH SLIDE PROJECTED IMAGES OF A BACKGROUND HORIZON SCENE, AND VARIABLE FOREGROUND OBJECTS

Post delineators. The simulated post delineators were implemented such that the reflecting head was 39 inches high and four feet from the road edge. They were placed at 31 foot intervals for the entire fixed portion of the curve (see Figure 31). The number of delineators, therefore, differed according to the length of the curve.

Chevron Alignment Sign (W1-8). The Chevron Alignment Sign is a vertical rectangle with a minimum size of 12 by 18 inches (Figure 26). These signs are implemented on the outside of a curve or sharp turn in line with and at right angles to approaching traffic.



W1-8
18"×24"

FIGURE 26. - CHEVRON ALIGNMENT SIGN

According to MUTCD guidelines, spacing was such that two signs were always in view, until the change in alignment eliminated the need for the signs. The simulator implementation consisted of a single projected slide with two or three signs, depending upon the length of the curve. The spacing of the signs was 30 to 50 feet. The two or three signs were located at the beginning of the fixed portion of the curve (see Figure 31).

Active (flashing) display. The flashing display consisted of two simulated beacons implemented horizontally on the top of the curve warning and advisory speed limit signs (see Figure 27).

FIGURE 27. - FLASHING BEACON WITH CURVE WARNING AND ADVISORY SPEED SIGNS

The left and right beacons flashed in an alternating pattern at a rate of one flash per second. The specific warning and advisory speed signs used are presented in Appendix L.

Patterned pavement markings. This pavement marking technique is non-standard and, therefore, no general specifications exist for implementation. The pattern was a herringbone, as schematized in Figure 28.

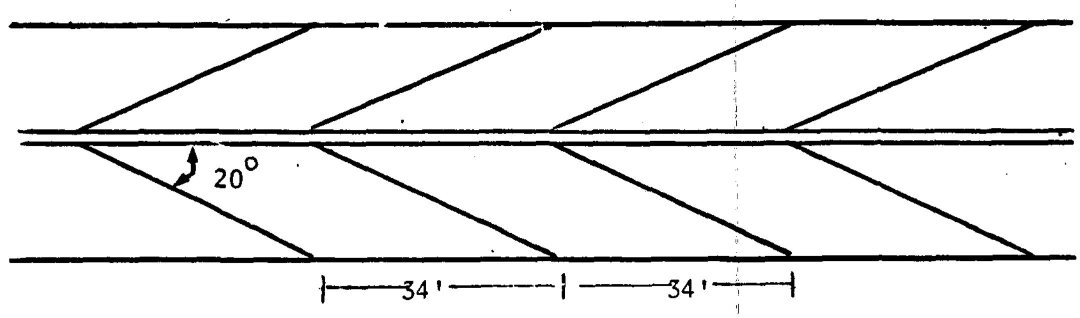


FIGURE 28. - PATTERNED PAVEMENT MARKINGS

The pattern started at the curve transition, which is 200 to 300 feet before the fixed portion of the curve, and continued through the entire fixed portion of the curve.

Countermeasure implementation. Edgeline treatments, post delineators, and the patterned pavement markings were implemented electronically and displayed through the CRT. Chevron alignment signs and the warning signs were presented through the slide projection system. All Chevron signs appeared on a single slide. The flashing beacon consisted of a slide with polarized material mounted in the positions of the beacons. The material for the two beacons was set 90° apart so that when a second polarized material located in front of the projector rotated, it had the effect of alternating the flashing beacons.

Subjects

Twelve licensed male drivers, aged 21-55 years old (verification of age was required), participated in the experiment. Males in this category are involved in the majority of alcohol-related crashes. Subjects were recruited through advertisements placed in local newspapers, on college bulletin boards, in college placement offices, and at the State Employment Office. Initial selection took place during a telephone interview, which included questions pertaining to personal data, driving experience, physical condition, drug and alcohol use, and availability (see Appendix G). Any individual who had used any hallucinogen, narcotic, barbituate, tranquilizer, or amphetamine more than three times during the previous 12 months was excluded from the study. Further, if a "yes" answer was given for any of the specific physical conditions listed on the Telephone Screening Sheet, the person was also excluded from the study. An additional screening form (Appendix B) was administered to each prospective subject to assess typical drinking behavior. Excessive drinkers or those without sufficient experience to attain the required BAC levels were eliminated through the screening. Use of the screening questionnaire is described in Appendix C.

Subjects who met these above criteria were invited to come in for an orientation session. At this session the project was described in detail (see Appendix K). After the description, the applicants took the Minnesota Multiphasic Personality Inventory (MMPI). The MMPI was scored, and one individual with a clinically abnormal personality (4-9 profile) was eliminated from further consideration. Individuals with a 4-9 profile tend to exhibit violence under alcohol. Each subject was required to sign an informed consent form (see Appendix H).

Driving Task

In each experimental session, the subject was instructed that his task was to drive continuously for approximately two hours. The two hour drive was selected to be consistent with the closed course experiment and to allow the evaluation of countermeasure effects over time. The subject was instructed to keep in the right hand lane in anticipation of oncoming traffic. The driving task included curve negotiation, obstacle avoidance, and attending to road signs. The event frequencies for the two scenarios are presented in Table 38.

TABLE 38. - SIMULATOR SCENARIO COMPONENTS

Scenario	Countermeasure Conditions	Additional Events	Required Response
Uneventful	75 curves/hr.	90 traffic signs/hr.	12/hr.
Eventful	75 curves/hr.	180 traffic signs/hr.	12/hr.
		60 unexpected obstacles/hr.	60/hr.

The spot treatment countermeasures were implemented on the curves. Randomly placed signs (about three signs/minute) occurred throughout the entire session. Subjects were instructed to respond to a specific subset of the traffic signs by honking the horn. Signs requiring this response occurred every five minutes.

All signs requiring a response had orange backgrounds. The order of presentation was random with one constraint: each sign occurred an equal number of times in each scenario. There were 18 random appearing scenarios (6/day). Therefore, each subject viewed each scenario twice. The specific signs used in the scenarios are shown in Appendix M.

The two scenarios differed only in that unexpected (moving) obstacles were included in the eventful drive. The obstacles always appeared on a straight road segment and resembled a car backing out of a driveway. A preview distance of 220 feet was used. To the subject, the obstacle appeared to be a large steel plate with no height. A ground plane schematic representation of the obstacle is presented in Figure 29.

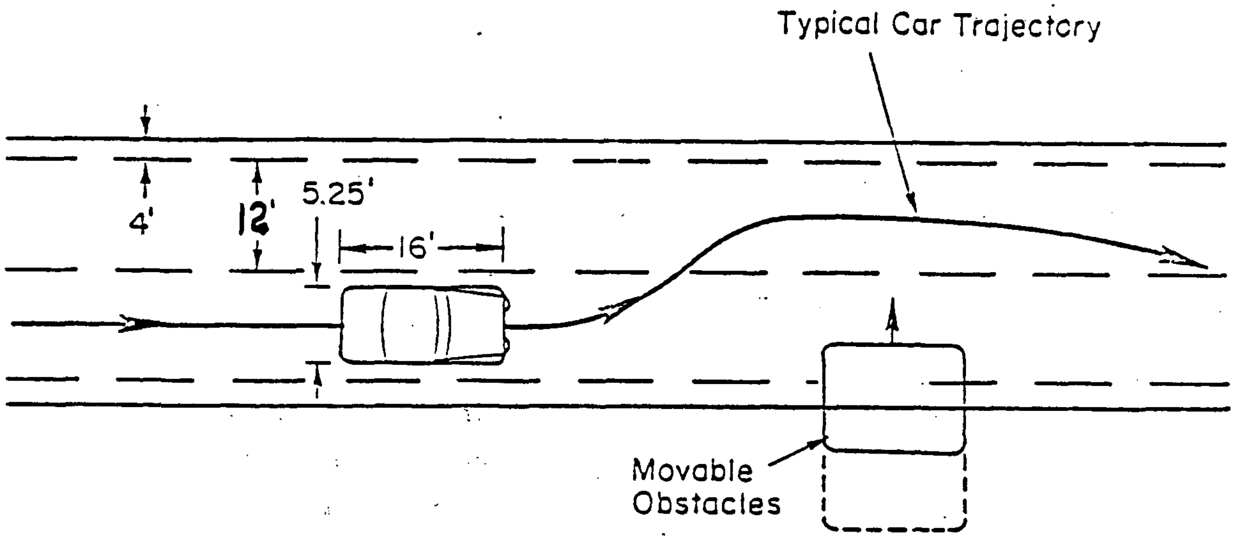


FIGURE 29. - GROUND PLANE REPRESENTATION OF THE UNEXPECTED OBSTACLE AVOIDANCE TASK

To simulate real-world driving motivations and risks, a monetary reward/penalty system* was used. Subjects were given a run completion bonus which was reduced for each penalty. Penalties were assessed for getting a speeding ticket or being in an "accident." Speeding tickets were given when the driver exceeded the posted speed limit and a police officer was present. An officer was present (i.e., siren sounded) about 30 percent of the time. "Accidents" were defined as hitting an obstacle or exceeding the lane boundaries by four feet or more. A loud "explosion" indicated accident occurrence. The performance bonus also depended upon how long it took to complete the drive. For each minute under two hours, a reward was given, while a penalty was assessed for each additional minute required beyond two hours. The monetary reward/penalty system is summarized below. Values are presented as computed for each twenty-minute segment.

Rationale for use of reward/penalty system is given in Appendix I.

$3.00	run completion bonus
$1.00	per minute time incentive relative to a reference time
$ .40	accident penalty
$ .20	ticket penalty
$ .10	missed sign penalty

Procedures

On experiment days, the subject was picked up and returned to his home by an STI escort. This ensured that no subject drove under the influence of alcohol acquired in the study. No subject was permitted to leave the experiment site until his BAC had dropped to 0.05% or below.

The dose and rate of feasible alcohol intake differed for subjects as a function of their previous drinking experiences. A sufficient number of alcohol beverage drinks was given to achieve the final peak BAC (.07 or .12%). All subjects received two drinks which had to be consumed within 40 minutes each. A third drink administered 80 minutes later was calculated to get the subjects to the maximum BAC.

Each drink contained an alcohol beverage diluted by an appropriate volume of some substance such as orange juice, etc. The diluting substance was at the subject's choice, except that no water was permitted. The final concentration of the drink was always 20% alcohol by volume, which prior studies have indicated is that concentration promoting fastest absorption. Placebo treatment for alcohol was diluted mixer (with a small amount of alcohol beverage floated on top) equal in volume to the alcohol plus mixer beverage.

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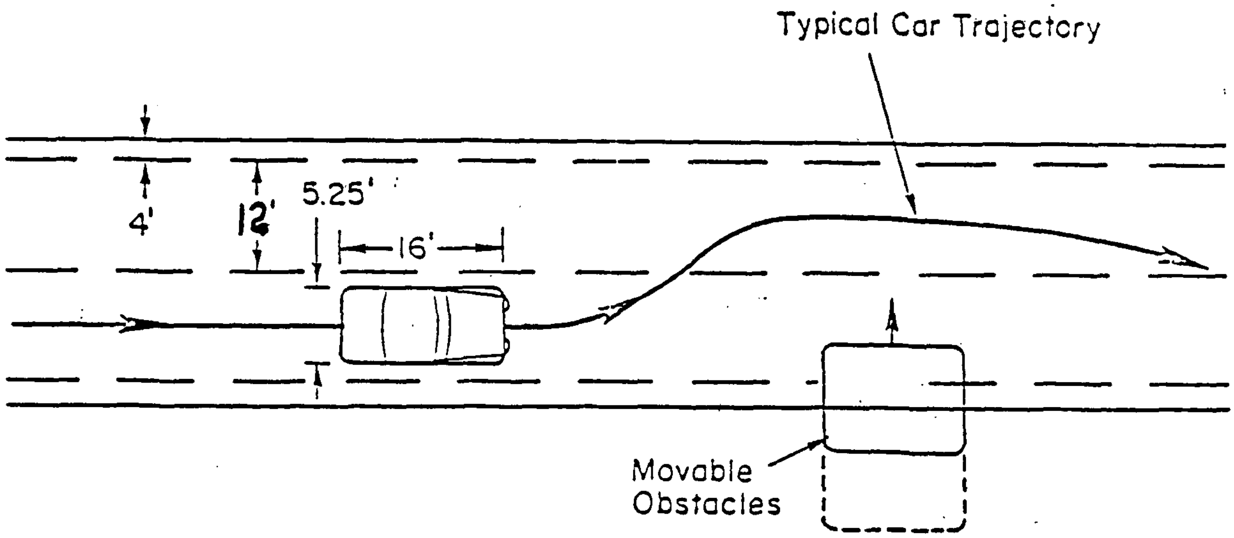

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A gas chromatograph alcohol breath analyzer (Intoximeter MKII) was used to measure BAC. BAC measurements were taken 30 minutes after completion of the final drink in order to achieve unbiased readings. A typical experimental day (target BAC = .12%) is presented in Figure 30.

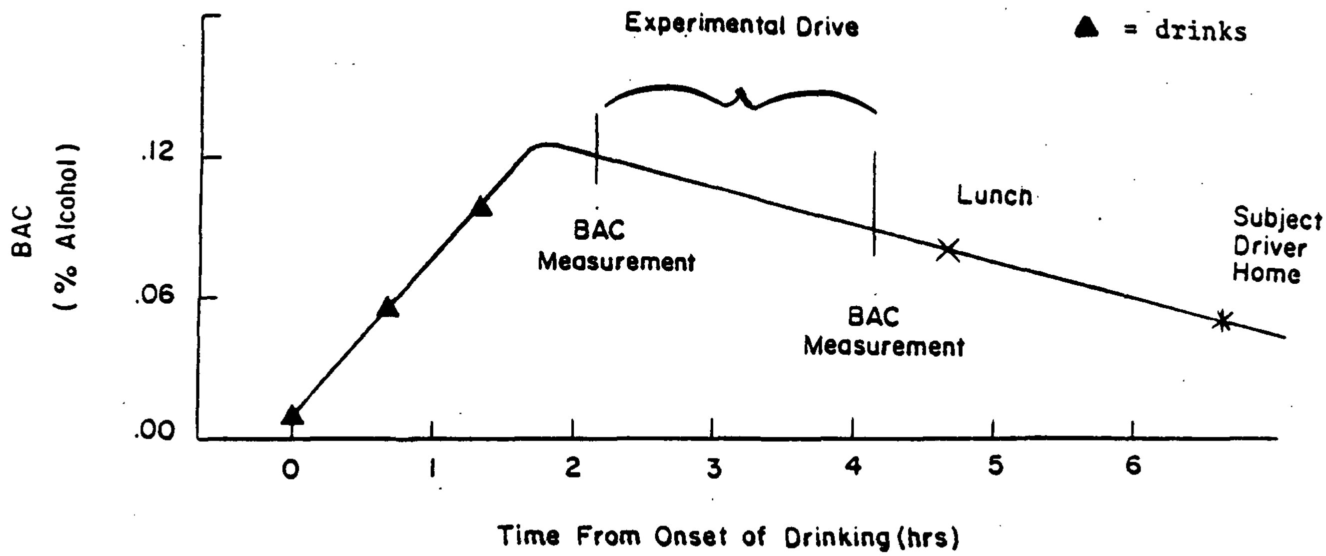


FIGURE 30 - TYPICAL EXPERIMENTAL DAY

Arrangements were in force with the Hawthorne Community Hospital, which is close to STI, to guarantee both access and payment for any subject who experienced medical problems during the course of the experiment. In addition, an answering service was engaged during the course of the experiment so that subjects could be directed to the experimenters or a physician if any post-experimental problems due to the experiment arose. Provisions for subject welfare at STI are described in Appendix J.

Training

Each subject received two or three training sessions, depending on how quickly he learned the task. The first session included indoctrination to the experiment as a whole, plus first encounter trials on the task. Performance was monitored throughout the training sessions, and if significant learning trends were still in evidence during the second session, then a third session was employed. Both subjective and objective criteria were used to determine whether additional training was necessary. The main subjective criterion was the judgment of the experimenter that each subject had adequately learned to drive the simulator. Objective criteria used to support this judgment included the ability to negotiate curves at the recommended speed and the ability to avoid the unexpected obstacle at the speed limit. Training sessions included drives which were approximately 15 to 20 minutes long.

Pilot Study

A small-scale pilot experiment was conducted to test the apparatus and experimental procedures. The apparatus includes the hardware changes made to implement the specific roadway countermeasures and the software developed to control the driving scenario and to collect and reduce the data. Experimental procedures evaluated included the use of a two-hour drive, and the associated alcohol dosing schedule. Because two hour drives had not been previously used at STI, the results of the pilot experiment provided information useful for establishing the specific rewards and penalties to be used in the main experiment. More importantly, the pilot runs allowed determination of the feasibility of the two hour drive, especially for alcohol-impaired subjects.

The pilot study was conducted in one day and used two subjects who were highly familiar with the STI driving simulator. Therefore, no screening or training was conducted. Each pilot subject completed one two-hour run at BAC=0.12%. One subject viewed the uneventful and one the eventful scenario.

Summary measures were examined for each 20 minute segment of the runs to determine of driving performance corresponded to previous data. Plots of the summary measures were examined to determine whether the two hour drive was feasible. Since no abrupt changes occurred in performance over successive 20 minute segments, the two-hour drive, even at the highest BAC level, was considered feasible.

4.2.4 Data Collected

Table 39 presents the driver performance measures recorded by the STI simulator. Data in Categories 1 and 2 were collected for all curves (150 in each two-hour drive). Straight road data (Category 3) were collected at five (800-foot) sections within each 20 minute segment (30 sections in each two-hour drive). The data in Category 4 were collected over the entire two-hour drive, with summary measures for each 20 minute segment of the scenario.

Figure 31 presents a schematic representation of the curve data collection. The data collection points 1 to 8 correspond to the spot data collection in Category 1 of Table 39. Point 9 corresponds to the beginning of the fixed portion of the curve where data in Category 2 of Table 39 were collected. The curve warning signs are located 650 feet before the beginning of the transition.

Missing Data

Because of illness unrelated to the alcohol dosing, one subject did not complete two of the 36 segments. These missing data were replaced using the mean values calculated from the scores of the other eleven subjects for the particular segments involved. Further, a computer error at STI resulted in the loss of 22 speed scores in the curve approach data. These data were also replaced using respective grand means of data from the other subjects.

TABLE 39. - DRIVER PERFORMANCE MEASURES FROM STI SIMULATOR

Data Category	Collection Location	Variables	Number of Samples
1	Curve approach and transition	speed lateral position heading error*	8 spot measures at 100 foot intervals
2	Fixed portion of curve	lateral position (1 foot intervals) lateral acceleration (0.05g intervals)	continuous
3	Selected straight road sections	lateral position (1 foot intervals)	continuous
4	Entire scenario		
	a. Frequency	number of obstacles struck number of speed exceedances	number of occurrences in each 20 minute segment
	b. Summary Scores	pay time to complete segment	summary score for each 20 minute segment
	c. Reaction Time (RT)	sign detection reaction time standard deviation of reaction time	mean for each 20 minute segment

*actual path relative to ideal path

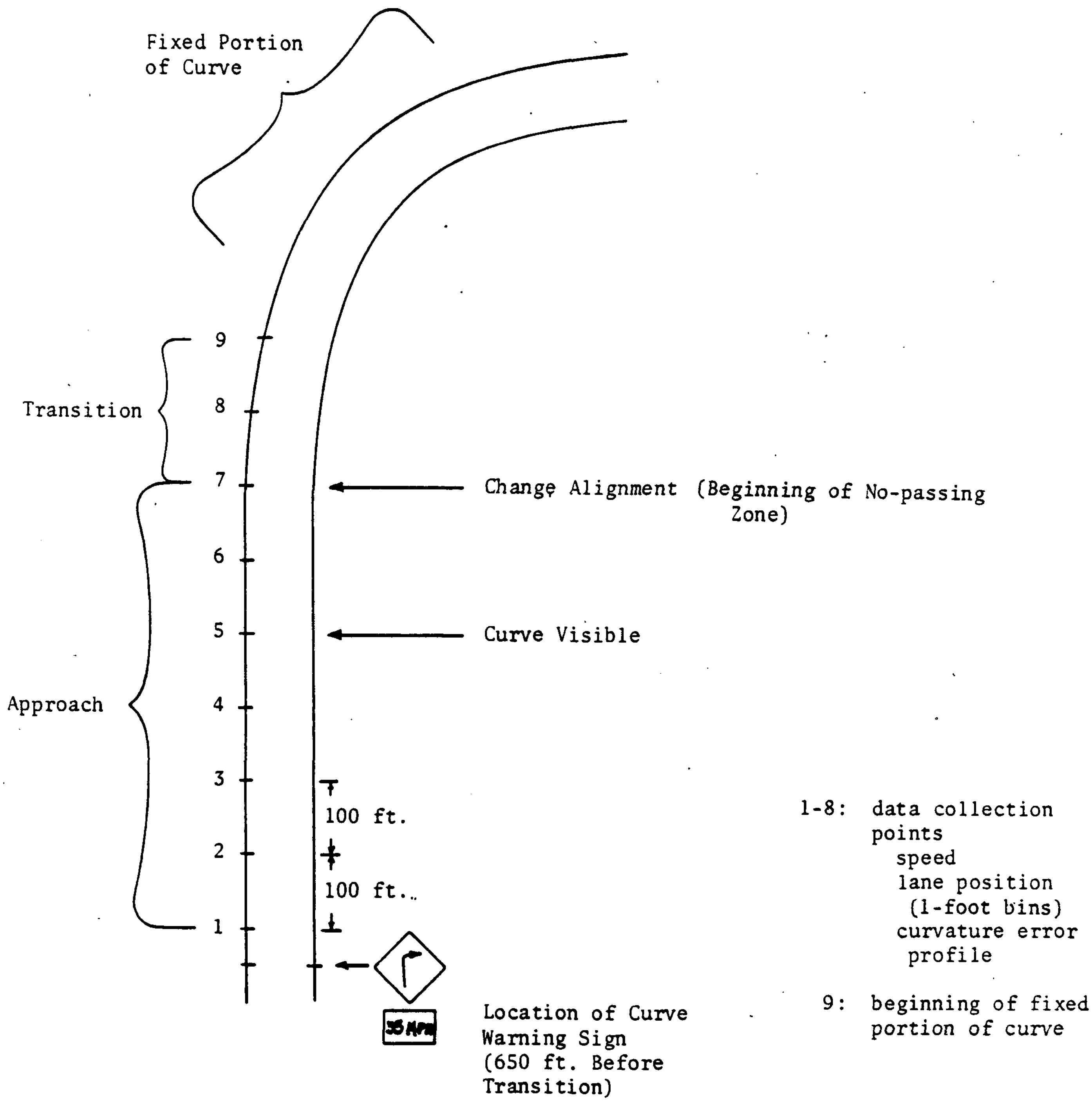


FIGURE 31. - CURVE DATA COLLECTION

4.2.5 Results

The analyses conducted on the STI simulator data follow the data collection format which was presented in Table 39. The primary results are presented in this section.

Curve approach and transition. The approach and transition to each curve was divided into seven intervals of 100 feet. Instantaneous measures of speed, lateral position and curvature error (defined as the actual path relative to an ideal path) were taken at the eight interval boundaries. Initial exploratory analyses were undertaken to examine the characteristics of the underlying distributions (mean, variance, skewness) and to identify transformations of variables which were normally distributed and exhibited reliable alcohol effects. Table 40 summarizes this effort. As indicated, subject's speed behavior in the curve approach and transition was generally not sensitive to BAC level. Two measures of lateral position and one of heading error exhibited changes under different BAC levels. To avoid potential problems associated with multiple analysis of non-independent data, only one transformation of each measure was selected for further analysis. Separate ANOVAs were conducted for each variable. The independent variables for each analysis were the same: subject, attentional demand, BAC, hour, edgeline, curve and spot treatment. Subject was treated as a random variable while the other six independent variables were treated as fixed factors. The main factors and their abbreviations are presented in Table 41.

Abbreviated source tables for the three ANOVAs are presented in Tables 42 - 44. Because of the complexity of the design, the tables present only main effects and significant two-way interactions.

TABLE 40. - CURVE APPROACH VARIABLES

Measure	Variable Form[1]	Interpretation	p> F Alcohol Effect[2]	Comment
Speed	P1	Approach speed	-	skewed distribution (-5.13)
	P8	Curve entry Speed	.31	
	P1-P8	Speed reduction	.63	
	$\frac{\Sigma P_{i+1}-P_i}{7}$	Mean deceleration	.63	
Lateral position	P8	Vehicle position at curve entry	.02	
	Log (Σ ABS (P_i-5))	Total error relative to center of lane	.00	Log transform to reduce positive skew
	Log (standard, deviation)	Standard deviation of lateral position over eight points	.65	Log transform to reduce positive skew
Heading error	P8	Error at point of maximum curvature	.08	
	ΣP_i	Total error	.00	

1 [1]p_i = i^{th} point along curve approach and transition (i = 1,8)

2 [2]If $p < .05$, the effect of alcohol on this variable was statistically significant.

TABLE 41. - ANOVA FACTORS

Factor	Level No.	Interpretation	Abbreviation
Demand	1	low = no obstacle avoidance	D1
	2	high = obstacle avoidance	D2
BAC	1	no alcohol	B1
	2	BAC = 0.07%	B2
	3	BAC = 0.12%	B3
Hour	1	first hour	H1
	2	second hour	H2
Edgeline	1	no edgeline	E1
	2	4-inch edgelines	E2
	3	8-inch edgelines	E3
Curve	1	curve no. 1*	C1
	2	curve no. 2	C2
	3	curve no. 3	C3
	4	curve no. 4	C4
	5	curve no. 5	C5
Treatment	1	no spot treatment	T1
	2	herringbone pavement markings	T2
	3	active display	T3
	4	chevron signs	T4
	5	post delineators	T5

*See Table 37 for curve dimensions.

TABLE 42. - CURVE ENTRY SPEED - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
Demand	(D)	1	918.63	0.39	.543
BAC	(B)	2	993.33	1.24	.310
Hour	(H)	1	749.55	5.41	.040
Edgeline	(E)	2	1327.10	10.39	.001
Curve	(C)	4	69861.00	221.11	.000
Treatment	(T)	4	60.73	0.96	.440
E x T		8	57.07	3.08	.004
C x T		16	48.29	2.70	.001

TABLE 43. - LOG TOTAL LANE POSITION ERROR - ANOVA

Source of Variance	Degrees of Freedom	Mean Square	F	p
Demand (D)	1	2.06	1.30	.279
BAC (B)	2	9.25	17.43	.000
Hour (H)	1	0.01	0.04	.842
Edgeline (E)	2	0.27	0.57	.574
Curve (C)	4	1.09	16.68	.000
Treatment (T)	4	0.46	4.10	.007
B x E	4	0.24	3.93	.008
D x C	4	0.22	5.13	.002
B x T	8	0.09	2.96	.006
C x T	16	0.16	3.00	.000

TABLE 44. - TOTAL HEADING ERROR - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	P
Demand	(D)	1	43.71	0.29	.602
BAC	(B)	2	1752.05	26.83	.000
Hour	(H)	1	2.71	0.10	.756
Edgeline	(E)	2	3.06	0.16	.857
Curve	(C)	4	570.13	14.98	.000
Treatment	(T)	4	60.20	5.06	.002
B x C		8	40.28	4.02	.000
H x C		4	23.81	3.15	.023
E x C		8	23.21	2.85	.007
C x T		16	18.38	2.06	.012

Curve negotiation. Following the curve approach and transition, drivers entered the (fixed radius) circular portion of the curve. During curve negotiation lateral position and lateral acceleration were recorded continuously. The output format was as follows:

Lateral position - The road was divided into 11 one-foot intervals defined below. In the analyses, intervals are referred to as bins.

Interval (Bin)	Definition
1	Vehicle on right shoulder
2	Right wheel near edge line
3-8	Vehicle in travel lane
9	Left wheel on centerline
10,11	Vehicle in oncoming lane

Intervals 5 and 6 represent vehicle position in the middle of the travel lane. Because the curves differed in length, the continuous measures were transformed into a measure of the percentage of time that the vehicle was located in each interval.

Lateral acceleration - Continuous measurements of lateral acceleration during curve negotiation were transformed so that the percentage of time within each of the following intervals was output.

Interval (Bin)	Lateral Acceleration (g)
1	$<.30$
2	.30 to .35
3	.35 to .40
4	.40 to .45
5	.45 to .50
6	.50 to .55
7	$>.55$

Initial exploratory analyses were conducted to examine the characterictics of the distributions of different transformations of these variables and to identify variables exhibiting sensitivity to alcohol level. These results are summarized in Table 45.

Of the curve negotiation measures, only the total number of lateral position bins exhibited sensitivity to alcohol. ANOVAs were run on this variable and MLATAC, the computed mean lateral acceleration over the entire fixed curve. The factors were the same as those from the previous analyses and are defined in Table 41. Abbreviated source tables are presented in Tables 46 and 47.

<u>Segment Summary Data</u>. For each twenty minute segment of data collection, summary measures were recorded, including the following variables:

<u>Number of obstacles struck</u> - For eventful demand sessions (Demand = D2) only, obstacle avoidance was required. Event frequency was one per minute, or 20 per 20 minute segment. This variable represents the error frequency of this subtask.

<u>Number of speed exceedances</u> - This variable represents the number of times per segment the driver changed from driving at or below the speed limit to above it.

<u>Time to complete segment (minutes)</u> - Since segments were fixed length driven, this measure represents average speed over the 20 minute segment.

<u>Pay (monetary reward)</u> - The reward per segment was computed from all of the previous measures as described on pages 127 and 128. This measure represents overall scenario performance.

TABLE 45. - CURVE NEGOTIATION VARIABLES

Measure	Variable Form	Interpretation	p > F Alcohol Effect	Comment
Lateral position	BIN1+9+10+11	% time outside travel time	.13	
	Total number of BINs used	Amount of road used	.00	
Lateral acceleration	BIN7	% time above .55g (tire threshold)	--	highly skewed (44.70)
	BIN4+5+6+7	% time above .4g	.41	
	MLATAC[1]	Mean lateral acceleration	.33	

[1]MLATAC - The percentage of time in each interval was multiplied by the midpoint of the interval. These products were summed to obtain a computed mean lateral acceleration.

TABLE 46. - AMOUNT OF ROAD USED - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
Demand	(D)	1	65.45	2.66	.131
BAC	(B)	2	365.74	16.44	.000
Hour	(H)	1	1.58	0.09	.773
Edgeline	(E)	2	71.43	9.86	.001
Curve	(C)	5	10636.00	159.84	.000
Treatment	(T)	4	12.83	2.43	.062
B x C		10	17.23	2.01	.039
E x C		10	12.31	2.40	.013
C x T		20	14.81	3.06	.000
B x T		8	6.033	2.35	.024

TABLE 47. - COMPUTED LATERAL ACCELERATION - ANOVA

Source of Variance		Degrees of Freedom	Mean Square	F	p
Demand	(D)	1	0.31	0.65	.436
BAC	(B)	2	0.19	1.16	.332
Hour	(H)	1	0.39	28.48	.000
Edgeline	(E)	2	0.26	12.88	.000
Curve	(C)	4	9.82	115.27	.000
Treatment	(T)	4	0.13	6.92	.000
H x C		4	0.02	3.32	.018
E x T		8	0.01	3.07	.004

Reaction time to signs - Signs were projected at different rates in the two DEMAND conditions (90 per hour - uneventful [D1], 180 per hour - eventful [D2]). However, only 12 per hour required response for both conditions. The mean reaction time (RT) and the standard deviation of reaction time (SDRT) were recorded for each 20-minute segment.

Separate ANOVAs were computed for each variable. The independent variables for each ANOVA were: BAC, HOUR, EDGELINE, and DEMAND[1]. No curve or spot treatment factors were included since each 20-minute segment included a full crossing of these two factors. The results of the ANOVAs are presented in Table 48.

[1]Demand = D2 only for number of obstacles struck.

TABLE 48. - SEGMENT SUMMARY DATA

Measure	$p > F$[1] Alcohol	$p > F$ Edgeline	Significant Main Effects	Significant Interactions	ANOVA dep. variable[2]
Number of obstacles struck	.001	.831	-	HxE (.030)	log (x+1)
Number of speed exceedances	.000	.612	-	HxE (.002)	log (x+1)
Time to complete (minutes)	.245	.000	Hour (.004)	-	log (x)
Pay (monetary reward)	.004	.013	Hour (.006)	BxH (.038)	x
Reaction time to signs (mean)	.306	.736	Hour (.015) Demand (.019)	-	log (x+1)
Standard deviation of reaction time to signs	.127	.600	Hour (.034)	DxB (.034)	log (x+1)

[1] $p > F$ is the level of significance of the F test in the ANOVA for the respective dependent variable ($\alpha = .05$ was used as the criterion).

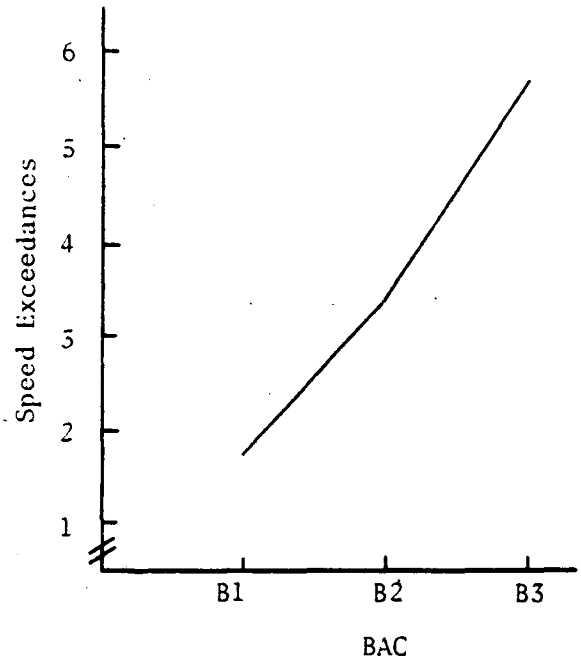
[2] x is recorded value. Log transformations were applied to variables with high positive skew. One was added to variables before transformation if distribution was centered near zero.

4.2.6 Interpretation of Results

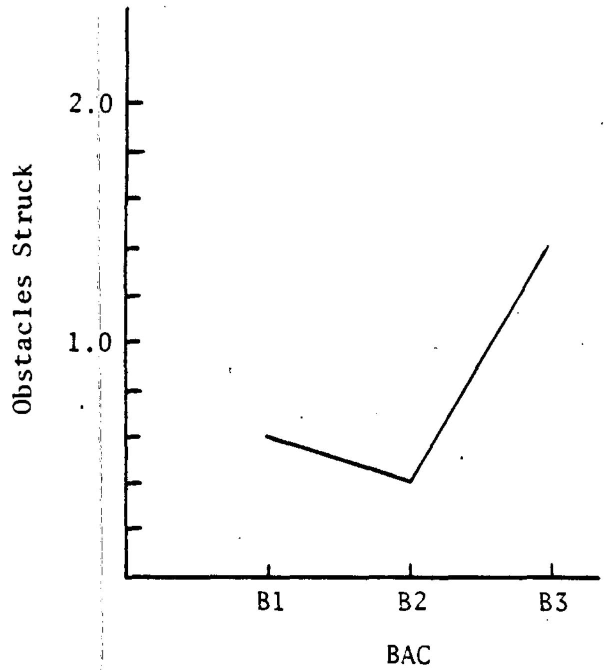
To determine the expected effects of the countermeasure treatments, it was first necessary to examine how alcohol influenced driving behavior in the STI simulator. In this section, the effects of alcohol are discussed first, followed by discussions of the edgeline effects, spot treatment effects, and interactive effects of the edgeline and spot treatment conditions. Effects of driving time and task demand are then considered.

Alcohol effects. The effects of alcohol (BAC) were most evident in the segment summary measures. Of the six measures listed in Table 48, three exhibited significant alcohol main effects. Using data from the high demand (D2) condition only, post hoc analyses (Newman-Keuls) revealed that subjects in the high BAC (B3) condition struck more obstacles per 20 minute segment than when sober (B1) or at the intermediate BAC level (B2). Speed exceedances were also significantly influenced by alcohol, with the number per segment increasing with BAC. According to post hoc analyses, all means were significantly different from each other.

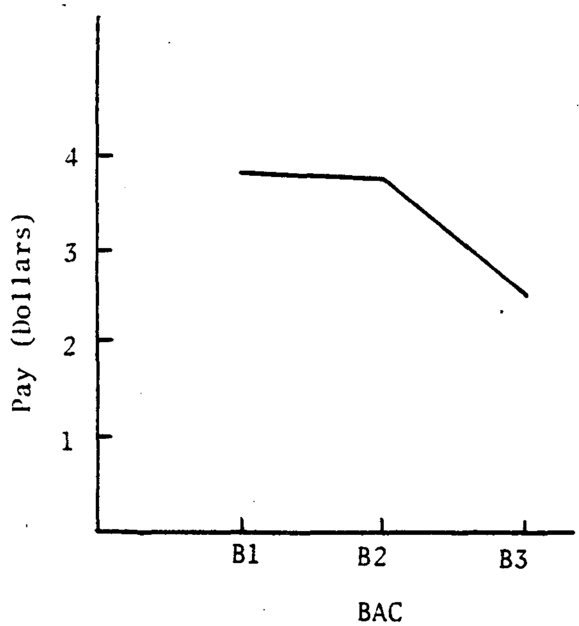
Pay (monetary reward) is the most general summary measure of driving performance, taking all rewards and penalties into account. For this variable, the alcohol effect was evident only at the high BAC (B3) condition. According to Newman-Keuls post hoc tests, the pay earned in the high BAC condition was significantly less than the pay earned in either the sober (B1) and low BAC (B2) conditions. These effects are shown graphically in Figure 32. From these graphs, the progressive effect of BAC on speed exceedances is evident, as opposed to the high BAC only effects associated with pay and the number of obstacles struck. It should be noted from Table 48 that alcohol had no reliable effect on time to complete the segment, which reflects overall driving speed. Alcohol also had no effect on the mean reaction time (RT) to signs nor on reaction time (RT) to signs nor on reaction time variability (RTSD).



(a) Speed Exceedances



(b) Obstacles Struck



(c) Monetary Reward (Pay)

FIGURE 32. - SIGNIFICANT ALCOHOL EFFECTS ON SEGMENT SUMMARY MEASURES

Alcohol effects in the curve approach were less apparent than on the segment summary measures. As shown in Table 40, eight measures were examined to determine alcohol impairment effects. For the three speed measures considered, alcohol had no overall effect. Alcohol did not effect the curve entry speed, the speed change during the curve approach, nor the mean deceleration over the approach. Alcohol did influence two measures of lateral position, including the position of the vehicle at the entrance to the curve and the total deviation (error) from the center of the lane. To make use of all of the lateral position information, total error was selected for analysis. Post hoc tests on this variable revealed that the total error at B3 was reliably greater than that at B1 or B2. As shown in Figure 33, the total error does clearly increase with BAC.

The third curve approach variable, heading error, was defined as the actual heading relative to a reference heading. Similar in concept to total lateral position error, this variable pertains more to where the vehicle is pointed, rather than where it is located. This variable thus incorporates an aspect of planning. The total heading error in the curve approach and transition was sensitive to alcohol. The effect reflects the difference between the high BAC (B3) condition and the other two BAC conditions (B1 and B2), as revealed by post hoc analysis (Newman-Keuls).

As shown in Table 45, only one measure of curve negotiation was sensitive to alcohol. The amount of road used in negotiation of the curves increased with BAC. Post hoc analyses revealed that all three treatment means were significantly different from each other. The percentage of time outside the travel lane during curve negotiations was not significantly influenced by alcohol.

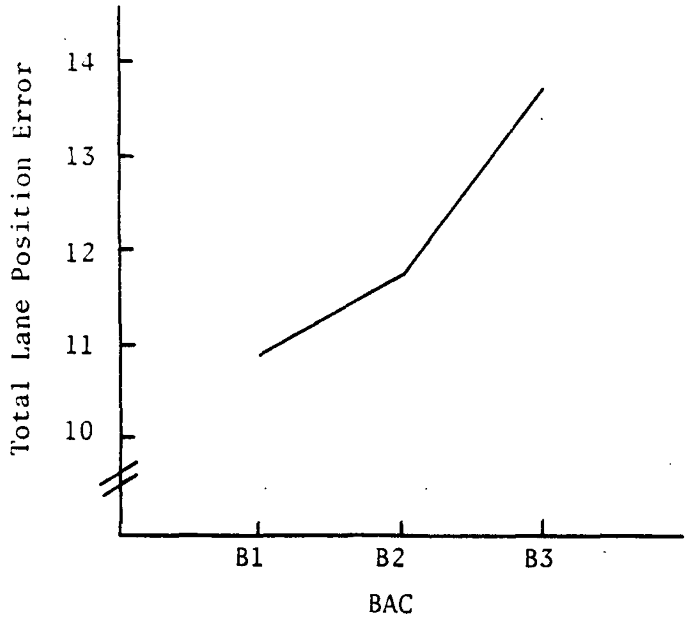
Two measures of lateral acceleration were also examined. Neither variable was sensitive to alcohol, indicating that in the simulator alcohol did not influence lateral acceleration in curve negotiation.

The significant alcohol main effects on measures of curve approach and negotiation are shown in Figure 33. Table 49 summarizes the findings on the effects of alcohol in the curve approach, negotiation, and segment summary measures. Table 50 summarizes the magnitudes of the effects.

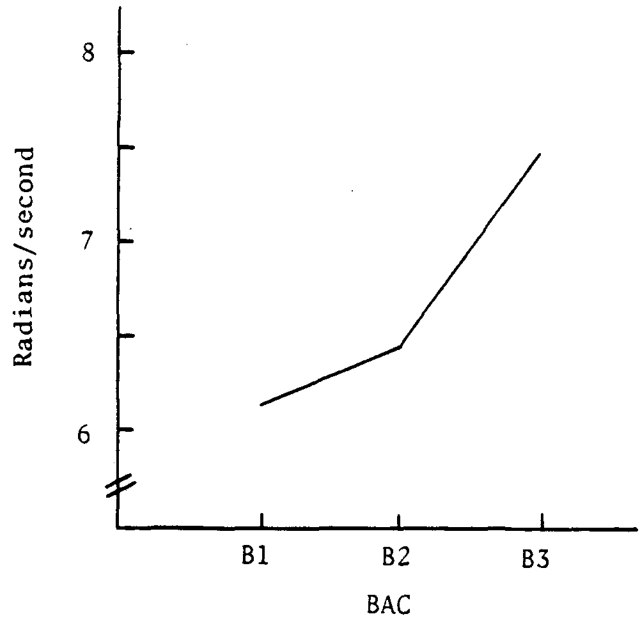
Edgeline Effects. The effects of standard and wide edgeline presence were determined through interpretation of the main effect of edgeline in each of the ANOVAs described above. Where a significant effect was observed, Newman-Keuls post hoc analysis were conducted to determine which conditions were significantly different. Edgeline effects were determined for the three categories of dependent measures: curve approach and transition, curve negotiation and segment summary measures. While the first two categories pertain to the immediate effects of edgelines in the approach, transition, and negotiation of horizontal curves, the third category allows evaluation of the general effects of standard and wide edgelines on overall performance in the simulator.

Considering the segment summary measures first, it was found that time to complete the driving segment and the pay (monetary reward) were both significantly influenced by the edgeline condition (Table 48). Post hoc analyses revealed no significant differences between the standard (E2) and wide edgeline (E3) conditions, indicating that for both variables, the effect was associated with edgeline presence, rather than with the wide edgeline condition. Regarding the direction of the effects, edgeline presence was associated with an increase in the monetary reward (i.e., overall driving improvement) and a decrease in the time required to complete the segment (faster overall speed). These effects are shown in Figure 34. Neither of the two summary measures which exhibited alcohol effects (obstacles, speed exceedances) were influenced by edgeline condition.

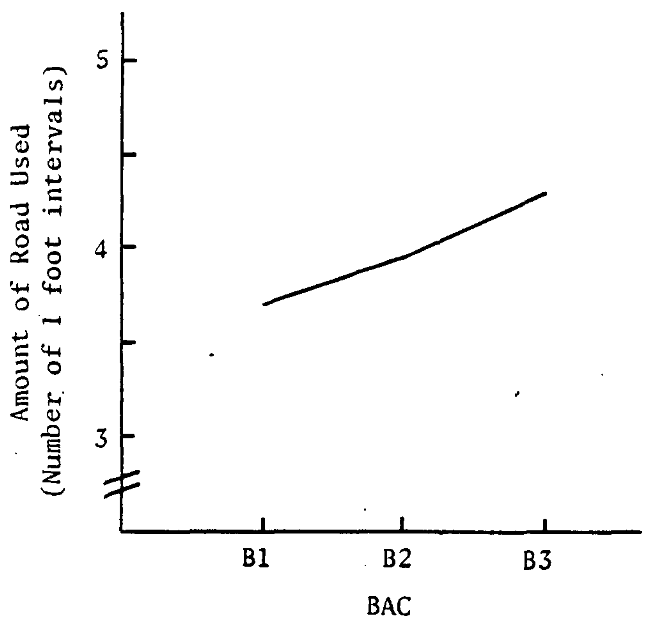
The edgeline main effect on curve entry speed was reliable (Table 42). Post hoc analyses on the means revealed that edgeline presence was associated



(a) Total Lane Position Error



(b) Total Heading Error



(c) Amount of Road Used
in Curve Negotiation

FIGURE 33. - SIGNIFICANT ALCOHOL EFFECTS ON MEASURES OF CURVE APPROACH AND NEGOTIATION

TABLE 49. - SUMMARY OF ALCOHOL EFFECTS IN STI SIMULATOR

Measure	Category	Alcohol Effect	Interpretation
Curve entry speed	Curve approach	No	
Total lane position error	Curve approach	Yes	Effect at B3 only[1]
Total heading error	Curve approach	Yes	Effect at B3 only
Mean lateral acceleration	Curve negotiation	No	
Amount of road used	Curve negotiation	Yes	Progressive increase[2]
Number obstacles struck	Segment measure	Yes	Effect at B3 only
Number of speed exceedances	Segment measure	Yes	Progressive increase
Pay (monetary reward)	Segment measure	Yes	Effect at B3 only
Time to complete segment	Segment measure	No	
Mean RT to signs	Segment measure	No	
Standard deviation of RT to signs	Segment measure	No	

[1] B3 > (B1 = B2), i.e., B1 and B2 were not different and both were significantly less than B3, with the exception of pay, where B3 < (B1=B2).

[2] All means were significantly different.

TABLE 50. - MAGNITUDE OF SIGNIFICANT ALCOHOL EFFECTS

Measure	B1	B2	B3	Difference	% Change	Unit	Interpretation
Speed exceedances	1.76	3.38		1.62	92	Frequency per 20 minute segment	Progressive increase with BAC
		3.38	5.71	2.33	69		
	1.76		5.71	3.95	224		
Obstacles struck	0.60		1.40	.80	133	Frequency per 20 minute segment	Effect at B3 only
		.41	1.40	.99	241		
Pay	3.83		2.49	-1.34	-35	Dollars per 20 minute segment	Effect at B3 only decrease
		3.75	2.49	-1.26	-34		
Total lane position error	10.91		13.71	2.80	26	Feet from center of travel lane summed over 8 points	Effect at B3 only
		11.73	13.71	1.98	17		
Total heading error	6.14		7.47	1.33	22	Radians per second	Effect at B3 only
		6.45	7.47	1.02	16		
Amount of road used in curve negotiation	3.70	3.93		.23	6	Number of one-foot bins used in curve negotiation	Progressive increase with BAC
		3.93	4.28	.35	9		
	3.70		4.28	.58	16		

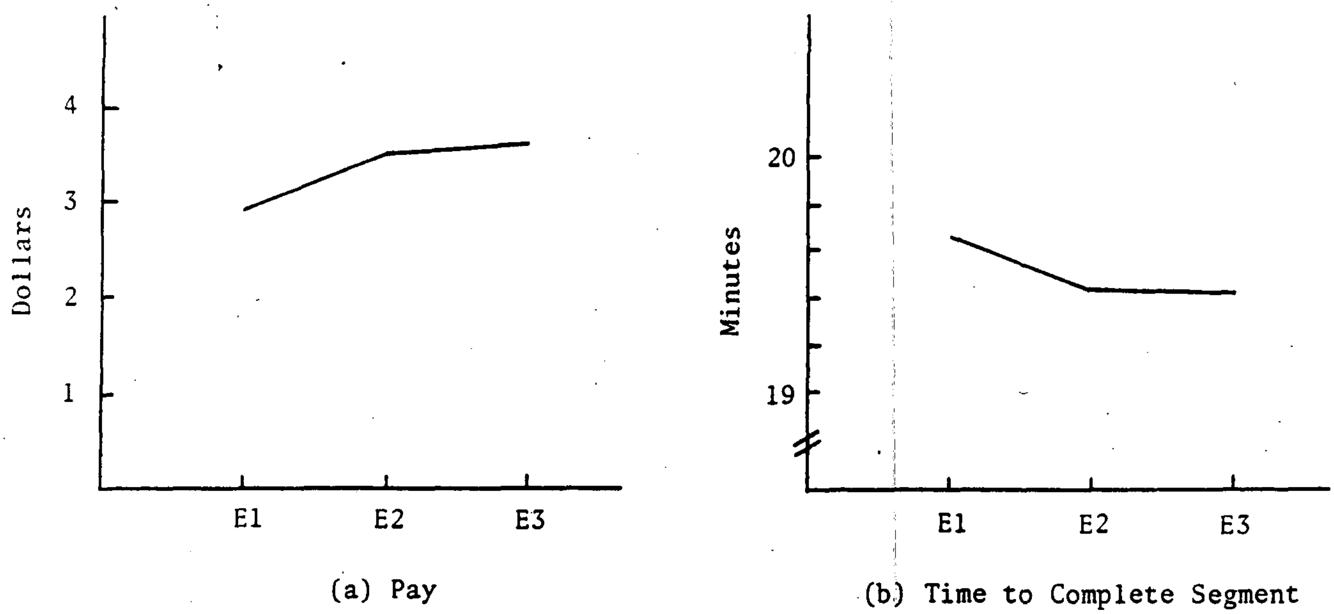


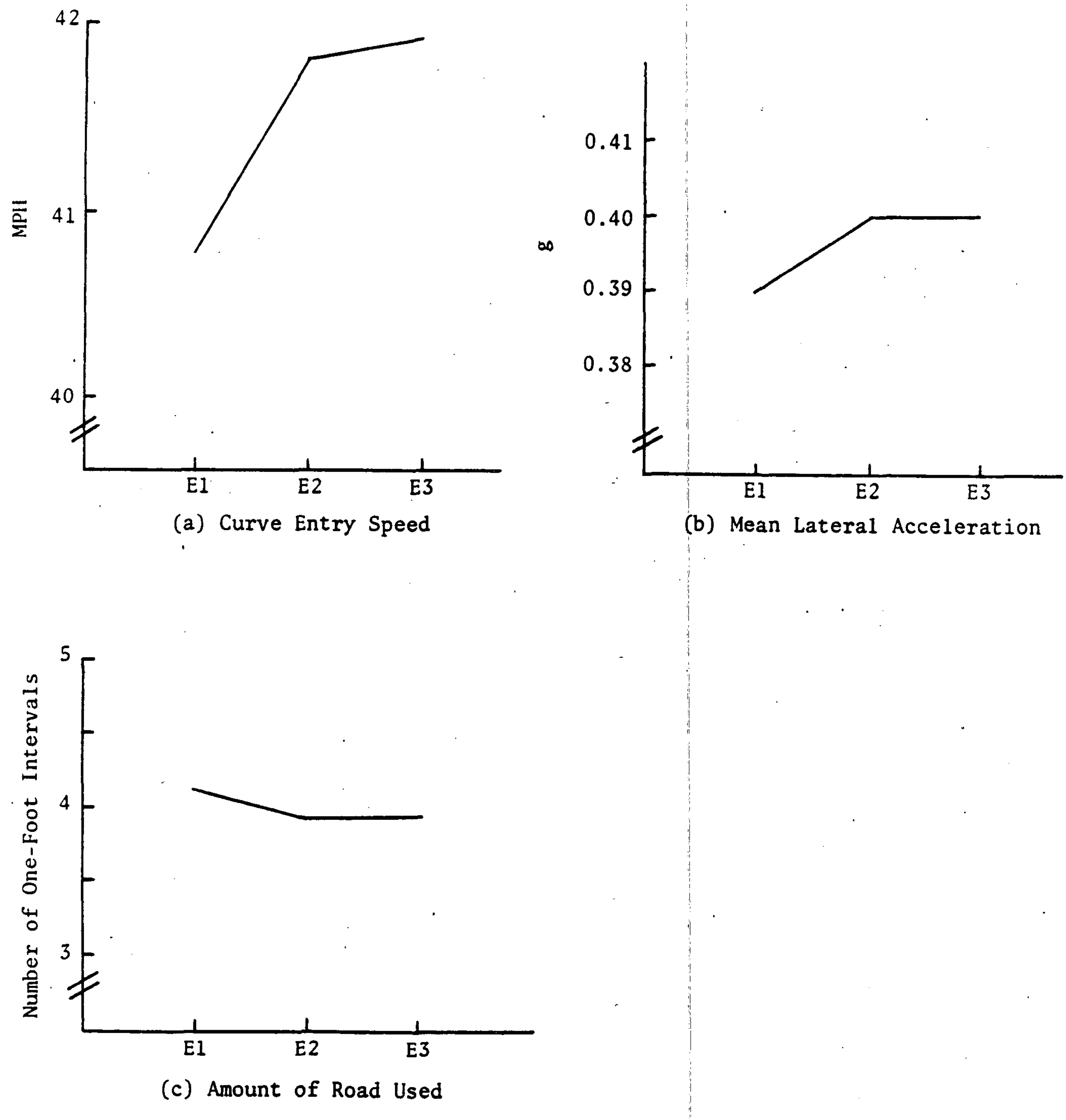
FIGURE 34. - EDGELINE EFFECTS ON SEGMENT SUMMARY MEASURES

with faster curve entry speeds. Wide edgelines were no different from standard edgelines in this measure. For the other two curve approach and transition performance measures, the effect of edgeline condition was not significant (Tables 43 and 44).

The two curve negotiation variables exhibited significant edgeline effects (Tables 46 and 47). Post hoc analyses indicated that edgeline presence significantly reduced the amount of road used in curve negotiation. The standard and wide edgeline conditions were essentially identical for this variable. Edgeline presence was also associated with a significant increase in the mean lateral acceleration in curve negotiation. The difference between the standard and wide edgeline conditions, again, was not significant. These effects are shown in Figure 35.

Table 51 summarizes the main effects of edgeline condition. Table 52 presents the magnitudes of the significant edgeline effects. It is apparent that where effects occurred, they were effects of edgeline presence rather than edgeline width.

Main effects of edgeline indicate a uniform effect over all BAC levels. To determine if edgelines had a differential effect on subjects at different BAC levels, the BAC x Edgeline interactions were examined. Of the dependent measures, only one exhibited a significant interaction. The measure was total lane position error in the curve approach. Post hoc analysis of the cell means revealed that at the high BAC level (B3), edgeline presence significantly reduced the total lane position error. The additional effect, associated with the wide edgeline condition was not significantly different from the standard edgeline condition. None of the means at the B2 condition were significantly different. However, at the B1 condition, wide edgelines were associated with greater error than standard edgelines. These data are shown in Figure 36.



(a) Curve Entry Speed

(b) Mean Lateral Acceleration

(c) Amount of Road Used

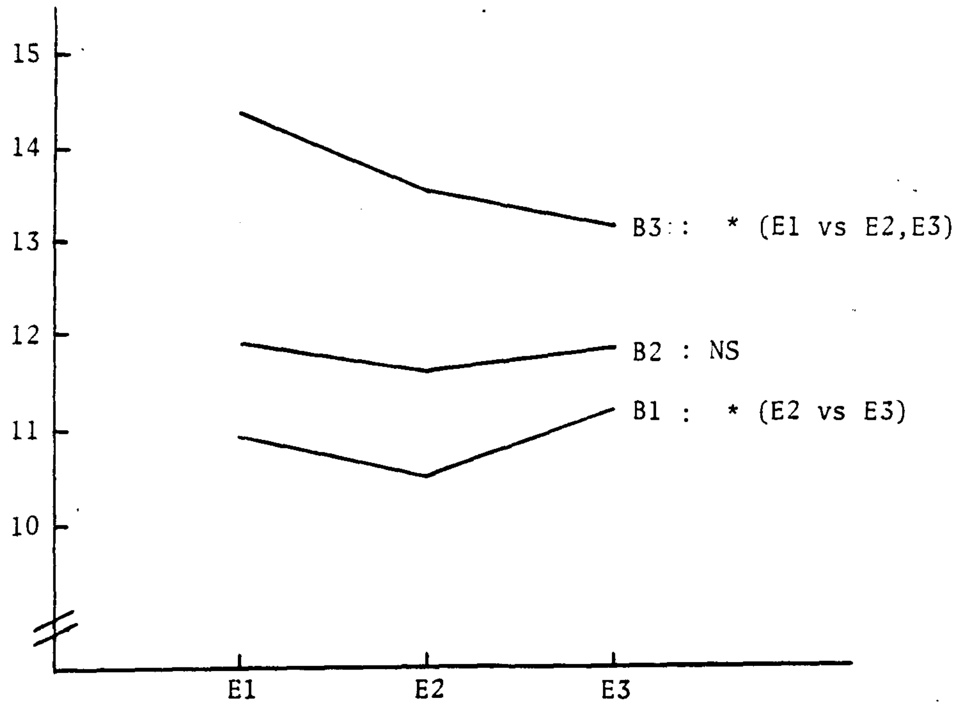
FIGURE 35. - EDGELINE EFFECTS ON CURVE APPROACH AND NEGOTIATION MEASURES

TABLE 51. - SUMMARY OF EDGELINE EFFECTS IN STI SIMULATOR

Measure	Category	Edgeline Effect	Interpretation
Curve entry speed	Curve approach	Yes	Edgeline presence increased speed. No additional wide edgeline effect.
Total lane position error	Curve approach	No	
Total heading error	Curve approach	No	
Mean lateral acceleration	Curve negotiation	Yes	Edgeline presence increased mean lateral acceleration. No additional wide edgeline effect.
Amount of road used	Curve negotiation	Yes	Edgeline presence reduced amount of road used. No additional wide edgeline effect.
Number of obstacles struck	Segment summary	No	
Number of speed exceedances	Segment summary	No	
Pay (monetary reward)	Segment summary	Yes	Edgeline presence increased pay. No additional wide edgeline effect.
Time to complete segment	Segment summary	Yes	Edgeline presence decreased time to complete the segment. No additional wide edgeline effect.
Mean RT to signs	Segment summary	No	
Standard deviation of RT to signs	Segment sumary	No	

TABLE 52. - MAGNITUDE OF SIGNIFICANT EDGELINE EFFECTS

Measure	BAC Level	Edgeline Condition E1(0")	E2(4")	E3(8")	Difference	% Change	Unit
Curve Entry Speed	All levels	40.8	41.8		1.0	2	mph
		40.8		41.9	1.1	3	
Mean lateral acceleration	All levels	0.39	0.40		0.01	3	g
		0.39		0.40	0.01	3	
Amount of Road Used	All levels	4.12	3.90		-0.22	-5	number of one-foot bins used
		4.12		3.89	-0.23	-6	
Pay (Monetary reward)	All levels	2.97	3.52		0.55	19	dollars
		2.97		3.58	0.61	21	
Time to complete segment	All levels	19.65	19.48		-0.17	-0.9	minutes
		19.65		19.42	-0.23	-1.2	
Total lane position error	B3 only	14.38	13.54		-0.84	-6	distance (feet) from center of travel lane summed over 8 points
		14.38		13.22	-1.16	-8	
	B1 only		10.53	11.30	0.77	7	



* : Significant differences identified through post hoc analyses
NS : Not significant

FIGURE 36. - TOTAL LANE POSITION ERROR BY EDGELINE CONDITION AND BAC

Comparison of edgeline and alcohol effects. Three of the eleven dependent measures exhibited reliable alcohol and edgeline effects. For two of these (monetary reward, Table 48; amount of road used, Table 46), the main effects of both factors were reliable. For the third measure (total lane position error, Table 43), the BAC main effect was significant, while the Edgeline main effect was not. The effect of edgeline was revealed through analysis of the reliable BAC x Edgeline interaction. As shown in Figure 36, the significant reduction in total lane position error was apparent only at the high BAC (B3) level. Cell means for the effects and associated magnitudes of change are presented in Table 53.

TABLE 53. - MAGNITUDE OF ALCOHOL AND EDGELINE EFFECTS ON MEASURES EXHIBITING BOTH EFFECTS

	Alcohol Levels				Edgeline Conditions				
Measure	B1	B2	B3	Diff.	E1	E2	E3	Diff.	Units
Monetary Reward (Pay)[1]	3.83	3.75		-0.08	2.97	3.52		0.55*	Dollars
	3.83		2.49	-1.34*	2.97		3.58	0.61*	
		3.75	2.49	-1.26*		3.52	3.58	0.06	
Amount of road used in curve negotiation[1]	3.71	3.93		0.22	4.12	3.90		-0.22*	Number of one-foot bins
	3.71		4.28	0.57*	4.12		3.89	-0.23*	
		3.93	4.28	0.35*		3.90	3.89	-0.01	
Total lane position error in curve approach[2]	10.91	11.73		0.82	14.38	13.54		-0.84*	Total distance (feet) from center of travel lane summed over 8 points
	10.91		13.71	2.80*	14.38		13.22	-1.16*	
		11.73	13.71	1.98		13.54	13.22	-0.32	

[1]Effect uniform across BAC levels

[2]Effect at high BAC (B3) only

*Denotes differences determined by Newman-Keuls tests to be significant

For all three measures, the magnitudes of significant alcohol effects were greater than the edgeline effects. Table 54 compares the magnitudes of the effects. For each of the three measures, the largest alcohol performance decrement, in each case representing the B1 vs B3 difference, was compared to both the effect of standard and wide edgelines. The edgeline effects were taken as a percentage of the alcohol effect.

TABLE 54. - COMPARISON OF ALCOHOL AND EDGELINE EFFECTS

Measure	Alcohol Effect	Edgeline Effect	% Reduction Alcohol Eff.[3]	Wide Edgeline Effect	% Reduction Alcohol Eff.	Units
Monetary Reward (Pay)[1]	-1.34	.55	41	.61	46	Dollars
Amount road used in curve negotiation[1]	.57	-.22	39	-.23	40	Number one-foot bins
Total lane position error[2]	2.80	-.84	30	-1.16	41	Total distance from center of travel lane summed over 8 points

[1]Effect uniform across BAC levels

[2]Effect at high BAC (B3) condition only

[3]The percent reduction of the alcohol effect is the edgeline effect as a percentage of the alcohol effect, irrespective of sign. For example, for monetary reward .55/1.34 = .41 or 41%; .61/1.34 = 46 or 46% reduction of impairment effect

The standard edgeline condition was associated with benefits of between 30 and 41 percent of the performance decrement associated with the B3 condition. For each measure, the wide edgeline condition was associated with an additional benefit relative to the standard edgeline condition, although as previously discussed, these additional benefits were not statistically reliable. The additional benefit was largest for total lane position error (11%, 41-30).

Spot treatment effects. The four spot treatments were hypothesized to influence behavior in the approach and negotiation of the horizontal curves. The effect of the spot treatments on segment summary measures was indeterminable due to the experimental design, that is, curve type and spot treatment were always crossed within each 20 minute segment. Spot treatment effects were determined through examination of the Treatment (T1-T5) main effects in the ANOVAs described in the previous section. Table 55 summarizes the main effects of Treatment and significant interactions with Treatment.

Newman Keuls post hoc analyses were conducted on the means of the variables which had significant Treatment main effects to see which of the treatments differed. It was determined that the patterned pavement marking (herringbone pattern, T2) was associated with a significant increase in the total lane position error in the curve approach, while the other three spot treatments (T3, T4, T5) were no different from the null condition (T1). This pattern was repeated for total curvature error where T2 was associated with significant increase, while the others had no effect. For the computed lateral acceleration in curve negotiation, T2 again was the only spot treatment to have a significant effect. The effect of T2 on curve negotiation was to reduce lateral acceleration.

The general absence of strong Treatment main effects combined with the consistent significance of the Curve x Treatment interaction effect, indicates that the spot treatments had different effects at the different curve types. (For curve dimensions refer to Table 37). Post hoc analyses on the C x T interactions were computed for several variables. Table 56 presents the results for the curve entry speed.

Treatment effects were determined separately for each curve. In the table the treatments are grouped according to the results of the post hoc analyses and the groups are arranged from slowest to fastest. The following points are noted from these data.

TABLE 55. - SPOT TREATMENT EFFECTS - SUMMARY OF ANOVA RESULTS

Measure	Category	Treatment Main Effect	Significant Interactions
Curve entry speed	Curve approach	No	E x T C x T
Total lane position error	Curve approach	Yes	B x T C x T
Total heading error	Curve approach	Yes	C x T
Amount of road used	Curve negotiation	No	C x T
Mean lateral acceleration	Curve negotiation	Yes	E x T

TABLE 56. - CURVE ENTRY SPEED
POST HOC ANALYSIS

Effect : Curve x Treatment

Mean Speed Groupings

Curve	Slowest ⟷ Fastest			
1	[T1 = T4]	[T2 = T5]		[T3]
2	[T1 = T5 = T2 = T4]			[T4 = T3]
3	[T1]	[T5 = T4 = T3]		[T2]
4	[T2]	[T5]	[T3 = T1]	[T4]
5	[T2]	[T5]	[T3]	[T4 = T1]

Key:

T1 - No spot treatment
T2 - Herringbone Pattern
T3 - Active Display
T4 - Chevron Signs
T5 - Post Delineators

[1] Brackets indicate groupings of means within a particular curve. Equal sign (=) is used to indicate no difference between treatment means.

1. For curves 1, 2 and 3, the no treatment condition (T1) was associated with the slowest curve entry speed, although for curves 1 and 2, the speed was not significantly different from other treatments.

2. Only at curves 4 and 5, were any other treatments associated with speed reductions at curve entry. For both curves, both the post delineators (T5) and the herringbone pavement marking pattern (T2) were associated with significantly slower speeds in curve entry.

3. At three of the five curves, curve entry speeds for the active display (T3) were significantly faster than for the no treatment condition. At two of the five curves, speeds associated with T3 were fastest of all conditions.

The Curve x Treatment interaction associated with the amount of road used in curve negotiation was also significant (Table 46). Post hoc analyses revealed significant spot treatment effects at Curve 3 only (S-shaped curve). For this curve only, three treatments (T3, T4 and T5) were associated with smaller values than T1 or T2, indicating a tracking improvement. This ordering of treatments was the same as the main effect of treatment (all curves), which approached significance ($p = .062$, Table 46.)

The Curve x Treatment interactions for total lane position error (Table 43) and total heading error in the curve approach (Table 44) were both statistically significant. Post hoc analyses, however, revealed no curve-specific treatment effects.

According to Table 43, a significant BAC x Treatment interaction was found for the total lane position error in the curve approach. Post hoc analyses revealed that at B1, both T2 and T5 were associated with significantly higher error than T1. At B2, T2 had the same effect, while at B3, no significant differences were obtained.

Edgeline and spot treatment interactions. One measure of curve approach behavior (curve entry speed) and one curve negotiation measure (mean lateral acceleration) exhibited significant Edgeline x Treatment interactions. Post hoc analyses revealed that in the absence of edgelines (E1), post delineators (T5) were associated with significantly slower curve entry speeds than those recorded in the no treatment (T1) condition. No significant effects were found in the presence of edgelines. Similarly, for mean lateral acceleration spot treatment effects occurred in the no edgeline condition. Lateral acceleration associated with the herringbone pattern (T2) was significantly less than for all other conditions (including no treatment condition). Post delineators (T5) in the no edgeline condition, were also associated with smaller lateral accelerations than the no treatment condition. No spot treatment effects were found in the presence of either standard or wide edgelines on this measure.

Based upon the Treatment main effects and the interactions with Curve, Edgeline, and BAC, the effects attributable to each of the four spot treatments are summarized in Table 57.

TABLE 57. - SUMMARY OF SPOT TREATMENT EFFECTS

Treatment	Measure	Effect	Interpretation[1]
Herringbone pavement markings (T2)	Curve entry speed	CxT	Reduction in speed at 2 curves only
	Total lane position error	T BxT	Increase in lane position error at B1, B2, but not at B3
	Heading error	T	Increase in heading error
	Lateral acceleration	T ExT	Decrease in lateral acceleration in absence of edgelines only
Active Display (T3)	Curve entry speed	CxT	Speed increased at 4 of 5 curves
	Total lane position error	BxT	Increased error at no BAC (B1) condition only
	Amount of road used	CxT	Decrease in amount of road used at one curve only
Chevron alignment signs (T4)	Curve entry speed	CxT	Speeds were faster at 2 curves only
	Amount of road used	CxT BxT	Decrease in amount of road used at 1 curve only, decrease at no BAC (B1) condition only
Post delineators (T5)	Curve entry speed	CxT ExT	Speed reduction at 2 curves only. Speed reduction in absence of edgelines only
	Amount of road used	CxT BxT	Decrease in amount of road used at 1 curve only, decrease at no BAC (B1) condition only
	Lateral acceleration	ExT	Decrease in lateral acceleration in absence of edgelines only

[1]Changes are significant ($p < .05$) differences from T1 (no treatment condition).

Driving time effects. The use of two-hour drives allowed examination of changes in driver performance over time. Significant main effects of Hour in the ANOVAs were interpreted as time-related performance changes. Interactions with BAC, Edgeline, and Spot Treatment were also examined. Of the eleven dependent measures, significant main effects of Hour were found for six (see Table 58).

Drivers tended to increase speed in the second hour of the experimental session as reflected by the significant Hour main effects of curve entry speed ($p = .040$, Table 42) and the time to complete each segment ($p = .004$, Table 48). None of the three tracking performance variables (total lane position, total heading error, and amount of road used in curve negotiation) exhibited significant effects of Hour. The computed lateral acceleration in curve negotiation was significantly higher in the second hour ($p = .000$, Table 47).

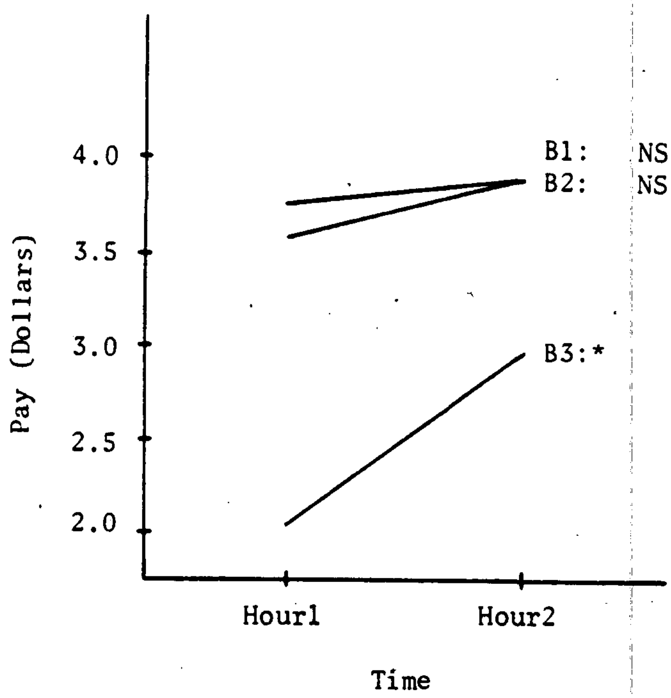
Neither the number of speed exceedances nor the number of obstacles struck exhibited a significant Hour effect. Reaction time to signs, however, was significantly a slower ($p = .015$, Table 48) in the second hour and reaction time variability was greater ($p = .034$, Table 48) during the second hour. Overall driving performance, as reflected in pay, increased significantly in the second hour ($p = .006$, Table 48). This effect was attributable to the high BAC (B3) condition as revealed in post hoc analyses of the significant BAC x Hour interaction. This effect is shown in Figure 37.

No other measures exhibited interpretable interactions with Hour.

Effects of task demand. As shown in Table 38, two scenarios were used in the experiment. The eventful condition (D2) differed from the uneventful (D1) in terms of the number of signs shown and the addition of an unexpected obstacle avoidance task. The effects of task demand were evaluated through interpretation of the main effects and interactions with Demand in the ANOVAs. None of the curve approach and negotiation measures exhibited significant main effects of Demand. One segment summary measure (RT to signs)

TABLE 58. - SUMMARY OF TIME EFFECTS IN STI SIMULATOR

Measure	Category	Time Main Effects	Interpretation
Curve entry speed	Curve approach	Yes	Faster in 2nd hour
Total lane position error	Curve approach	No	
Total heading error	Curve approach	No	
Mean lateral acceleration	Curve negotiation	Yes	Greater in 2nd hour
Amount of road used	Curve negotiation	No	
Number obstacles struck	Segment measure	No	
Number of speed exceedances	Segment measure	No	
Pay (monetary reward)	Segment measure	Yes	Greater in 2nd hour
Time to complete segment	Segment measure	Yes	Less in 2nd hour
Mean RT to signs	Segment measure	Yes	Slower in 2nd hour
Standard deviation of RT to signs	Segment measure	Yes	Greater variability in 2nd hour

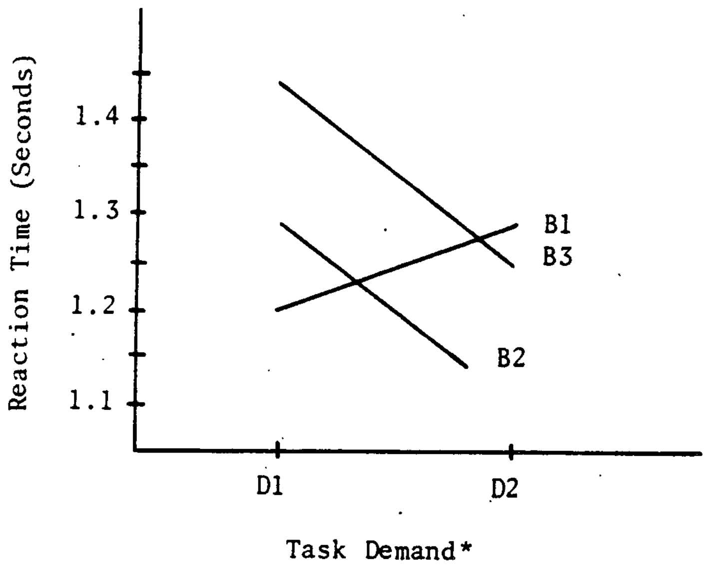


*: Significant difference identified through post hoc analyses.

NS: Not significant

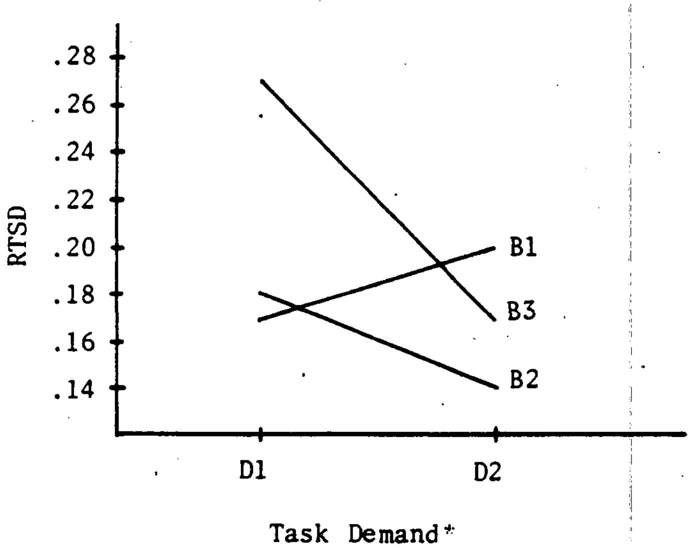
FIGURE 37. - MONETARY REWARD (PAY) BY TIME AND BAC

exhibited a significant Demand effect (p = .019, Table 48). Examination of the cell means revealed that the RTs associcated with the higher demand scenario (D2) were faster than in the lower demand scenario. This reflects behavior in the two alcohol conditions (B2, B3) as shown by the Demand x BAC interaction (Figure 38). Reaction time variability also decreased in the high demand scenarios for the two alcohol conditions as shown in Figure 39.



*D1 - Uneventful Scenario
D2 - Eventful Scenario (includes Obstacle Avoidance)

FIGURE 38. - REACTION TIME BY TASK DEMAND AND BAC



*D1 - Uneventful Scenario
D2 - Eventful Scenario (includes Obstacle Avoidance)

FIGURE 39. - STANDARD DEVIATION OF REACTION TIME (RTSD) BY TASK DEMAND AND BAC

5. DISCUSSION OF EXPERIMENTAL RESULTS

It was initially intended that the two experiments be designed to allow direct comparison of results. In that regard, there are several aspects which are common to both experiments, including the two-hour experimental runs, the three BAC levels, and the number of experimental sessions per subject. In addition, the simulator scenario (uneventful) was designed to be consistent in terms of task demand with the closed course at TTI. Beyond these factors, however, the two experiments differed largely because of the constraints of the two data collection systems. The DPMAS had the capability of continuous recording of selected measures of driving performance. Selected measures included speed, lateral position, and lane deviation frequency. Data were obtained from a straight road section and a long relatively gentle curve, in addition to the continuous recording of lane deviation frequency. In the STI simulator, data collection focused on driving performance in the approach and negotiation of curves. Performance measures were limited by processing limitations of the computer control system to instantaneous measures at predefined locations or summaries of continuous measures. The overall performance measures obtained in the simulator also were not comparable to those obtained in the closed course experiment. Therefore, although the driving simulator offered a greater variety of stimulus conditions and the capability of evaluating different treatments under identical simulated conditions, the DPMAS offered greater overall flexibility in the amount and type of data collected.

In comparing the results of the two experiments, the most obvious difference is in the amount of data collected. With the STI simulator, essentially all required data were collected. Only two twenty-minute segments for one subject (less than one percent) were missing. The experience with the DPMAS, however, was considerably less successful. As discussed in Section 4.1.6, data were lost for many reasons. For some measures, only 25-30 percent of the data required by the original experimental design were obtained. The resulting loss of analytical power was significant and as a result, the usefulness of the DPMAS data was reduced. However, the data that were collected did allow conclusions concerning the effects of alcohol and the countermeasure treatments.

5.1 General Discussion - Experiment I

The overall evidence in support of the effectiveness of the rumbling treatments was not strong. Whether this is a real effect, indicating that such treatments do not have potential for improving the driving performance of alcohol-impaired drivers, or is due to the substantial loss of power resulting from the large proportion of missing or non-reliable data is difficult to determine. The fact that the effects of alcohol were generally reliable and consistent with previous research indicates that sufficient analytical power was retained in the data collected for demonstration of alcohol effects and that the debilitating effects of alcohol were stronger than improvements in performance associated with countermeasure presence.

5.1.1 Alcohol Effects

With regard to the effects of alcohol, the major findings were generally consistent with previous results and the predicted directions of the effects. Lane position errors, defined in this experiment as deviations from the test course travel lane, were found to increase with alcohol. The increase in left-side deviations was primarily a high BAC phenomenon, while the right-side lane deviations frequency increased monotonically with BAC. Although infrequent, the distribution of "accident" events (i.e., lane deviations of at least four feet) indicated an alcohol effect. All nine recorded accidents occurred in the high BAC condition.

The observed effects of alcohol on measures of overall driving performance were also consistent with previous research. For example, Attwood et.al., (1980) have argued that alcohol generally increases the variability of driving performance. In this experiment, the variability of both speed and lateral position exhibited reliable increases with BAC. The effects were observed for both the straight and curved road sections of the test course and were evident at both alcohol conditions (BAC2 and BAC3). The variabilities were higher on the curve than on the straight road section, indicating a wider range of speeds and use of more of the travel lane in curve negotiation than in straight road driving.

The effects of alcohol on mean velocity suggest that when impaired, drivers failed to exert appropriate caution in curve negotiation. The effect of alcohol on straight-road speed indicated a slight nonsignificant increase with BAC. Respective curved-road speeds in the BAC1 and BAC2 conditions were slower than the corresponding straight-road speeds, indicating that when sober (BAC1) or at low BAC (BAC2), drivers generally reduced speed for curve negotiation. However, the close proximity of the straight and curved road mean speeds for the BAC3 condition indicates a failure of the drivers in the high BAC condition to reduce speed for curve negotiation. The nonsignificance of the straight-road speed increase supports this interpretation, rather than one suggesting a general speed increase with BAC.

The effects of alcohol on vehicle lateral position were not strong. On the curved road only, alcohol was associated with an overall movement away from the centerline and toward the edgeline.

5.1.2 Driving Time Effects

The use of two-hour experimental sessions allowed examination of changes in driving performance and countermeasure effects over time, as well as interactions with alcohol effects. Relative to the effects of alcohol, performance decrements associated with driving time were not strong. Three variables exhibited significant time-related changes: right side lane deviation frequency and speed variability both increased with time, while the mean straight-road velocity decreased over time. Of interest is the observation that the time-related effects occurred between different time segments. The significant increase in right-side lane deviation frequency occurred between the first and second thirty-minute time segments, while the primary increase in speed variability occurred in the fourth time segment. Straight-road velocity decreased progressively between the first and last time segments.

If performance decrements over the two-hour experimental drive can be interpreted as fatigue effects, the BAC x Time segment (SEG) interactions can be interpreted as fatigue-alcohol interactions. In the experiment only three measures exhibited significant BAC x SEG interactions. Curved-road mean velocity decreased significantly over time for drivers in the sober (BAC1) condition. A similar time-related but nonsignificant speed reduction was observed in the BAC2 condition. In the high BAC condition, however, curved-road velocities increased slightly over the first three time segments, and decreased in the fourth segment to a speed close to the first segment speed. Several interpretations of these results are possible. First, if it is assumed that an overall time-related speed reduction reflects an increasingly drowsy driver, the absence of this effect for drivers in the high BAC condition indicates that the high dose of alcohol somehow interferred with the progressive drowsiness observed at the other two BAC conditions. Previous research (e.g., Barry, 1974) has identified a facilitating effect of alcohol in certain tasks, but this is usually associated with a small rather than large dose.

Alternatively, the time-related speed reduction could reflect an increase in caution adopted by drivers to compensate for their perceived drowsiness. The presence of this effect for drivers in the sober and low BAC condition is more consistent with this interpretation in that drivers in these two conditions are less impaired, and thus presumably more likely to be sufficiently aware of their performance to adopt caution as necessary. Unfortunately, such conclusions must be considered as speculative since the question of the drivers' awareness of their condition and their intent to compensate by adopting caution cannot be determined from the data obtained in this experiment.

The time between successive left-side departures increased for the sober and low BAC conditions over time, while remaining fairly constant for the high BAC condition. This further supports the argument that drivers in the sober and low BAC conditions were more aware of their behavior than drivers in the high BAC condition, in that the time-related speed reductions were associated with improved tracking performance. In the high BAC condition both speed and left-side deviation frequency did not change appreciably over time.

Lateral position variability on the straight road, a measure of the amount of road used, increased over time for drivers in the two alcohol conditions, while decreasing for drivers in the sober condition. This effect is more consistent with a synergistic alcohol-fatigue effect where the performance decrement associated with alcohol is exacerabated with time.

Comparison of the alcohol and driving time effects indicates that the experimental task is a better test of alcohol than of fatigue effects. This was not unexpected, in that the majority of experimental fatigue paradigms used sessions of much longer than two hours. The use of alcohol in this experiment necessitated a shorter experimental drive.

5.1.3 Effects of Simulated Rumbling Treatments

Evaluation of countermeasure effectiveness requires appropriate criteria. In this experiment, the objective was to first identify "behavioral errors" associated with alcohol impairment. If increased BAC was associated with a significant increase in a particular measure, an observed reduction associated with a countermeasure treatment condition could then be interpreted as a positive benefit. Countermeasure effects on measures which did not exhibit alcohol effects were more difficult to interpret. In this situation it was necessary to refer to previous research to determine whether an observed effect could be interpreted to reflect a positive or negative effect.

Based upon the observed effects of alcohol, positive countermeasure effects are defined as follows:

- reduction in frequency of lane deviations
- increase in time between successive same-side deviations
- reduction in time outside the travel lane per deviation
- reduction in the standard deviation of velocity
- reduction in the standard deviation of lane position
- reduction in mean velocity, especially in curve negotiation

The presence of the rumbling treatments did not significantly reduce the number of lane deviations recorded. However, for left deviations, the BAC x Countermeasure interaction approached significance and indicated a reduction in lane deviation frequency at the high BAC condition. Optimistically, it is felt that if a higher percentage of the data had been obtained, this effect would have been reliable. The time between successive left side deviations was greater in the presence of the countermeasure treatments. The main effect for this measure approached significance. The BAC x Countermeasure interaction was significant, indicating a positive benefit at the high BAC condition. Time outside the travel lane was not influenced by the countermeasure presence.

The measures of general driving performance should be considered less direct indications of countermeasure effectiveness. This is because the analysis did not take into consideration the actual number of times in each condition the countermeasure was experienced. This would be particularly problematic at the sober and low BAC conditions where lane deviations and therefore countermeasure activations were relatively infrequent. Nevertheless, there were some positive effects associated with the presence of the treatments. For both the straight and curved road sections, the overall effect of the countermeasure presence was to increase mean velocity. However, the significance of both BAC x Countermeasure interactions indicates a more complex effect. For drivers in the sober and high BAC conditions, countermeasure presence was associated with increased speed. For both the straight and curved road sections, the increases associated with the high BAC condition were statistically reliable, while those observed in the sober condition were not. The effect of countermeasure presence in the low BAC condition was to reduce mean velocities, indicating a positive countermeasure benefit. The reduction was significant only on the curved road.

Countermeasure presence was associated with a reduction of straight road speed variability in the two alcohol conditions, as compared to an increase associated with the sober condition. None of the effects was significant, despite the significance of the BAC x Countermeasure interaction effect.

The countermeasure presence was associated with a significant overall reduction in the variability of lateral position on the curved road, however, the significance of the BAC x Countermeasure interaction indicated a non-uniform effect across BAC levels. The reduction was observed for drivers in the sober and low BAC conditions, while an increase in this measure was observed for drivers at the high BAC condition. On the straight road, the results indicated a uniform, although nonsignificant reduction associated with countermeasure presence.

The countermeasure presence had a significant effect on vehicle placement (mean lateral position) on the straight road only. The effect was to move drivers, at all BAC levels, toward the centerline, away from the simulated shoulder rumbling treatment.

In terms of the criteria established above, the rumbling treatments did exhibit some positive effects. Unfortunately, the majority of the positive effects were not statistically reliable. The main exceptions were the speed reduction found on the curved road for drivers in the low BAC condition, and the overall significant reduction in speed variability on the curved road. Although the paucity of data on "accident" occurrence precluded statistical analysis, it is noteworthy that only one of nine recorded "accidents" occurred in the presence of the countermeasure treatments.

The difficulty of interpretation due to lost or missing data was considered above as a possible reason for failure of the observed effects to attain statistical significance. In this regard, it should be noted that a number of the performance measures exhibited statistically significant interactions between countermeasure presence and BAC. Post hoc tests were subsequently computed to determine the countermeasure effects at different BAC levels. The majority of these tests revealed no reliable differences. However, the significance of the interaction effects indicates that the countermeasure treatments were having different (even if nonsignificant) effects at different BAC levels. This was true for the following measures: time between successive left-side deviations, straight-road speed variability, and curved-road lateral position variability. The significance of the interaction effects and subsequent failure of the simple component effects to attain statistical significance suggests that the loss of power due to small cell frequencies associated with the post hoc tests was primarily responsible for the results.

If this is true, it should be noted that in terms of the effectiveness criteria identified above, the significant BAC x Countermeasure interactions indicated some negative countermeasure effects at certain BAC levels, which in addition to the positive effects, may also have been reliable with a larger data set. For example, in the sober condition, the countermeasure presence was observed to reduce the time between successive left-side lane deviations, indicating an undesirable increase in frequency. It was also noted that the countermeasure presence was associated with significant speed increases at the high BAC condition as well as nonsignificant increases in the sober condition. Lateral position variability on the curved road section was observed to increase in the presence of the countermeasure treatments, reflecting an effect which has also been associated with alcohol impaired driving.

5.2 General Discussion - Experiment II

In the driving simulator, data were collected to evaluate both continuous (i.e., edgelines) and spot roadway treatments. The data collected permitted more comprehensive analysis of the effects of edgelines than the spot treatments since, due to the experimental design, the segment summary measures could not be used to evaluate the spot treatment effects. This was unfortunate since these measures proved to be especially sensitive to alcohol. However, since the expected effects of the spot treatments were localized, analysis of performance in the approach and negotiation of curves was most appropriate for evaluation of their effects.

As discussed above, countermeasure effectiveness was defined for this experiment as the reduction of "behavioral errors" associated with alcohol-impaired driving. The data analysis plan called for determination of alcohol effects ("errors"), and use of these measures as criteria for treatment efectiveness. This approach was intended to reduce the difficulty of interpretation since it would thus be shown that a treatment had reduced or eliminated a specific impairment effect of alcohol which had been observed in the driving simulator. The relative strengths of the impairment and countermeasure effects could also be compared directly using the respective magnitudes of change for a particular measure. In the absence of error reduction effects, it was more difficult to interpret countermeasure effects as positive or negative, especially in the driving simulator where the relation of performance measures to comparable measures of on-road driving cannot necessarily be assumed to be direct, due to inherent differences between the simulator and on-road driving. Fortunately on several performance measures, both alcohol and countermeasure effects were found, thus allowing a quantitative determination of the error reducing potential of the treatments.

5.2.1 Alcohol Effects

Six of eleven dependent measures exhibited significant effects of alcohol. Three segment summary measures (number of obstacles struck, number of speed exceedances, and monetary reward) were influenced by alcohol. Monetary reward was the most general measure of overall driving performance, taking all rewards and penalties into account. The alcohol-related decrement on this measure was apparent only at the high BAC level, indicating that drivers at the low BAC level could perform essentially as well as drivers when sober, in the driving simulator. Consistent with this effect is the effect of alcohol on the number of obstacles struck. On this measure, performance was essentially the same at the sober and low BAC conditions, with a significant increase at the high BAC level. As with overall scenario performance, this result indicates that when mildly impaired, the drivers could perform the obstacle avoidance task as well as when sober.

The third segment summary measure, speed exceedance frequency, exhibited a progressive effect of alcohol, indicating significant impairment effects at both alcohol conditions. Speed exceedances were recorded every time the travel speed changed from below the established speed limit to above it. Since curve negotiation required speeds below the 55 mph limit, it was generally not possible to drive the simulator at an excessive speed for an extended period of time, without incurring a road departure accident. The fact that speed exceedance frequency was sensitive to alcohol while the total time to complete the scenario segment was not, indicates that the number of speed changes, but not the overall speed, was influenced by alcohol. Speed exceedance frequency can thus be interpreted as a crude measure of speed variability. This interpretation, however, requires the assumption that the overall mean speed is close to the speed limit,* such that an increase in speed exceedance frequency reflects an increase in the range of driving speeds.

The fact that the increase in speed exceedance frequency at the low BAC level is not reflected as a decrement in monetary reward can be explained by the relation of speed exceedance frequency to the reward/penalty structure upon which monetary reward was based. To simulate real-world driving, a recorded speed exceedance resulted in a speeding ticket (penalty) only 30 percent

*The curve approach speed at P1, (farthest point from each curve) was the best estimation of mean travel speed in the data collected. The grand mean for this variable was 54.36, which is very close to the 55 mph speed limit.

of the time, such that the majority of speed exceedances would not be reflected in the monetary reward.

Further support for the conclusion that in the simulator alcohol affected speed variability more than overall speed is provided by the absence of alcohol-related speed effects in the curve approach. None of several measures of curve approach and entry speed behavior was influenced by alcohol. Of interest also is the negative finding concerning lateral acceleration in curve negotiation. Alcohol had no appreciable effect on this measure. The measures of tracking performance in the curve approach and negotiation, however, were significantly influenced by alcohol. The total lane position error, defined as the sum of the distances of the vehicle from the center of the travel lane at eight points in the curve approach and transition and the total heading error, defined as the sum of the absolute differences between the vehicle heading and the ideal heading at the same eight points, were both significantly increased by alcohol. The effect on total lane position error was relatively weak, while the effect on heading error reflected a difference between the high BAC condition and the other two conditions. Tracking behavior in curve negotiation, in terms of the amount of travel lane used, also increased with alcohol. Although increases were observed at both alcohol conditions, only the difference between extreme conditions (B1 vs B3) was statistically significant.

Johnston (1983) has argued that use of tracking measures alone, such as lateral position variability, as criteria for curve negotiation are not adequate for analysis of driver performance on curves. This is due to the common practice of "curve cutting", in which drivers select a curve with a radius less than the actual curve. Tracking error measures such as those used in this study, he argues, cannot reveal this phenomenon. While the evidence for "curve cutting" is strong, several factors lessen the importance of this argument for interpretation of the present results. First, although "curve cutting" was evident in Johnston's study, the evidence suggested that alcohol did not have a strong effect on this behavior. Interpretation of countermeasure effects on such a measure, as discussed above, was made difficult without a defined impairment effect. Second, a consideration of the major differences between driving a simulator versus an actual vehicle suggest that curve-cutting may not be as prominent in the driving simulator. On the assumption that curve-cutting is an attempt to reduce the lateral acceleration in curve negotiation, the absence of motion cues in the simulator argues against its occurrence. Because lateral acceleration was recorded in the driving simulator, one could expect increases in curve cutting to be associated with a reduction in the mean lateral acceleration in curve negotiation. The absence of an alcohol effect on lateral acceleration, together with the significant alcohol-related tracking decrements, provide further support to the conclusion that curve-cutting is not as prevalent in the simulator as in on-road driving behavior.

5.2.2 Edgeline Effects

Five of eleven dependent measures exhibited significant edgeline effects. Three of these measures (monetary reward, amount of road used in curve negotiation, total lane position error in the curve approach) also had significant alcohol effects, thus allowing a comparison of the magnitudes of the two effects. In each case, the magnitude of the performance improvement associated with edgeline presence was between 30 and 41 percent of the magnitude of the performance decrement associated with the high alcohol level. For each variable, the wide edgeline condition was associated with an incremental benefit of between 1 and 11 percent of the performance decrement, although none of the wide edgeline effects was statistically reliable. The incremental wide edgeline benefit was smallest (1%) on the amount of road used in curve negotiation, and greatest (11%) on the total lane position error in the curve approach. The magnitude of the latter effect may be related to the fact that the edgeline effect on total lane position error was evident only at the high BAC level, while the edgeline effects for the other two measures represented effects across all BAC levels. From these results it can be concluded that edgeline presence reduced the effects of alcohol impairment in both the immediate demands of curve negotiation, and in overall driving performance.

Interpretation of the other three measures significantly affected by edgeline presence was less straightforward. None of these measures (curve entry speed, mean lateral acceleration and time to complete the segment) was influenced by alcohol. In the absence of alcohol effects, criteria for establishing countermeasure effectiveness rely on established relations with safe driving. Reductions in speed and lateral acceleration have generally been considered as indications of safe driving. The finding that edgeline presence increased curve entry speed and mean lateral acceleration, while decreasing time to complete the segment could be interpreted as suggestive of increased risk-taking. However, if this were true, we could expect edgeline-associated increases in other measures of unsafety (e.g., number of obstacles struck). The above-discussed increase in pay which reflects overall safety, and the improving tracking on curves are also inconsistent with this interpretation. Therefore, it must be concluded that edgeline presence increased overall speed (decreased time), speed in the approach to curves, and lateral acceleration in curve negotiation, without adversely affecting tracking accuracy in the curve nor overall safety. It should be noted, finally, that the absence of significant wide edgeline effects may be related to the difficulty of presenting edgelines in the driving simulator which appear to be twice as wide as the standard edgelines. According to the experimenter, at least one subject noted that the standard and wide edgeline conditions were difficult to distinguish in the simulator.

5.2.3 Spot Treatment Effects

The overall effects of the spot treatments on performance in the driving simulator were not strong. Although three measures exhibited significant Treatment main effects, post hoc analyses revealed these effects to be attributable primarily to the herringbone pattern of pavement markings. The general absence of strong main effects, together with the reliable interactions with the Treatment factor, indicates that the effects were not uniform across curve types, edgeline conditions, and BAC levels. In addition, the measures affected were generally not those which had exhibited alcohol impairment effects, which made it difficult to interpret the results as positive or negative. The effects associated with each spot treatment are summarized briefly:

Herringbone patterned pavement markings. The effects of this treatment were most uniform across curve types, as revealed by the post hoc analysis of Treatment main effects. Three measures exhibited significant effects of the herringbone pattern with non-reliable Curve x Treatment interactions. The effects, however, indicated tracking decrements associated with this treatment. Lane position error in the primarily straight curve approach increased in the presence of the patterned pavement markings, although this effect was evident only in the sober and low BAC conditions. A uniform increase in heading error in the curve approach was also associated with this treatment. The treatment did, however, reduce lateral acceleration in curve negotiation, but only in the absence of edgelines. It also was associated with reduced entry speed at two of the five curves.

Taken together, these findings suggest that the herringbone pattern caused confusion in identifying the center of the travel lane, and that drivers reduced lateral acceleration, and possibly speed* while negotiating the part of the road on which the pattern was implemented.

Flashing beacons on curve warning signs. The absence of treatment main effects associated with this treatment indicates no uniform effects across curves or BAC levels. This treatment was associated with a significant speed increase at four of the five curve types. It was also associated with an increase in lane position error in the sober condition only, and a decrease in the amount of road used in curve negotiation, at one curve only. Of the effects associated with this treatment, the increase in curve entry speed was most evident, occurring at four of the five curves. This speed increase may be attributable to the fact that the curve warning signs were located well in

*No measure of speed was available for curve negotiation.

advance of the curve entrance, such that any beneficial effects would have occurred before the point at which curve entry speed was recorded.

Although not apparent in the alcohol conditions, the increase in total lane position error in the curve approach, observed for drivers in the sober condition only, is an apparently detrimental effect. This effect, together with the increased curve entry speeds, suggests that after passing the flashing display, the drivers concluded that driving would be uninterrupted by the discrete events requiring a specific response (sign or obstacle avoidance), thus allowing an increase in the travel speed in the curve approach. The carryover effects of this treatment into the curve were minimal as reflected by the tracking improvement observed at one curve (S-shaped) only.

Chevron alignment signs. No uniform effects of this treatment were found. Its presence was associated with increased entry speeds at two curves, and a decrease in the amount of road used at one curve only. This latter effect was evident only in the sober condition, and would therefore not qualify as a reduction of an alcohol impairment effect. In the absence of tracking decrements associated with this treatment, the increased curve entry speeds can be interpreted as increased certainty about the demands of the curve.

Post delineators. A reduction of curve entry speed (2 curves only) and a reduction of lateral acceleration in curve negotiation, both in the absence of edgelines only, were associated with this treatment. A tracking improvement at one curve only, and only in the sober condition, was also associated with this treatment. As with the previous treatment, the tracking improvement cannot be interpreted as the reduction of an alcohol impairment effect, since it was evident only in the sober condition. The reductions in curve entry speed and lateral acceleration, which occurred only in the absence of edgelines can be interpreted as indicative of increased uncertainty about the curve.

Table 59 summarizes the effects of the four spot treatments by categorizing the effects as reductions of impairment effects, other positive effects, and negative effects. For this presentation, reductions of speed and lateral

TABLE 59. - SUMMARY OF SPOT TREATMENT EFFECTS

Treatment	Reduction of Impairment Effects	Other Positive Effects	Negative Effects
Herringbone pavement marking pattern	none	decreased lateral acceleration (no edgeline condition)	increased total lane position error (sober and low BAC conditions)
		reduced curve entry speed (2 curves)	increased heading error (all conditions)
Active (Flashing) beacons	decreased amount of road used in curve negotiation (1 curve)	none	increased curve entry speed (4 curves)
			increased total lane position error (sober condition)
Chevron alignment signs	none	decreased amount of road used in curve negotiation (sober condition)	increased curve entry speeds (2 curves)
Post delineators	none	decreased curve entry speeds (2 curves, no edgelines)	
		decreased amount of road used in curve negotiation (sober condition)	
		decreased lateral acceleration (no edgeline conditions)	

acceleration are interpreted as positive effects even though an increase in driver uncertainty may have been indicated in the discussion above. The qualifying conditions, identified through interpretation of the interaction effects, are indicated parenthetically.

As indicated in the table, only one spot treatment exhibited an effect which could be interpreted as the reduction of an alcohol impairment effect, and this effect was evident at one curve only. The post delineator condition was the only treatment without negative effects. However, the positive effects associated with this treatment were evident primarily in the absence of edgelines, indicating possible driver uncertainty.

Two of the spot treatments (chevron alignment signs and post delineators) were associated with tracking improvements in the sober condition only. The flashing beacons were associated with a tracking decrement in the curve approach in the sober condition. The treatment effects on curve entry speed differed according to the method of treatment presentation. The flashing beacons and chevron alignment signs, both presented via slide projection were associated with increased curve entry speeds, while the herringbone pavement markings and post delineators, which were computer generated, were associated with speed reductions in curve entry. Overall, the results were equivocal concerning the potential benefits of any of the treatments.

5.2.4 Effects of Driving Time

Several effects of driving time were exhibited in the driving simulator. Drivers were observed to increase overall speed, curve entry speed, and lateral acceleration, while at the same time increasing overall performance (monetary reward). Reaction time to signs and reaction time variability both increased in the second hour. The results suggest a general shift of attention over time away from the discrete sign response task to the continuous tracking component of driving.

5.2.5 Effects of Task Demand

With the addition of the obstacle avoidance task, drivers were found to reduce their reaction times to signs and reaction time variability. These effects were apparent in the two alcohol conditions but not in the sober condition. None of the measures of performance in the curve-approach and negotiation exhibited effects of task demand.

6. SUMMARY AND CONCLUSIONS

6.1 Experiment I

1. Alcohol effects in the closed-course experiment were strong and generally consistent with previous research. Alcohol increased the frequency of lane position errors (deviations from the travel lane), and accident events. It also increased the variability of speed and lateral position. Alcohol effects on speed indicated a failure of drivers in the high BAC condition (0.12%) to reduce speed in curve negotiation.

2. Effects of driving time (fatigue) were evident, but not as strong as alcohol effects. Increases in right-side lane deviation frequency, and speed variability, and a gradual decrease in mean velocity were found over the two-hour experimental drive. Evidence suggesting a fatigue-alcohol interaction on curved-road velocity was found.

3. The overall evidence supporting the effectiveness of the rumbling treatments was positive although not strong. Only two measures (speed and speed variability) exhibited significant reductions in the presence of the countermeasures. Several additional measures ("accident" frequency, left-side lane deviation frequency, lateral position variability) revealed positive although statistically non-reliable effects. The results indicated that the rumbling treatments had differential effects according to BAC level on several measures.

4. Because of the amount of data lost or missing, the adequacy of the data for determining rumbling treatment effectiveness can be questioned. The positive directions of the effects indicated that with increased analytical power, the effects may have been statistically reliable.

6.2 Experiment II

1. In the simulator study, alcohol effects were evident primarily on measures of tracking behavior and overall scenario performance. At the high BAC level (0.12%) drivers were generally more variable in their tracking behavior in the approach and negotiation of curves. Overall performance measures which exhibited sensitivity to alcohol included frequency of obstacles struck, monetary reward, and speed exceedance frequency. The latter measure indicated increased speed variability associated with alcohol.

2. Edgeline presence was found to improve tracking behavior in both the approach and negotiation of curves, and to increase overall simulator performance, as reflected in increased monetary reward. The performance improvements were approximately 30 to 40 percent of the performance decrements observed in the high BAC condition. Wide edgelines were associated with incremental performance benefits of between 1 and 11 percent, although they were statistically not significant. Edgeline presence was also associated with increases in curve entry speed and lateral acceleration in curve negotiation, which in the context of the observed tracking improvements, were interpreted as evidence of increased driver certainty.

3. Spot treatment effects in the driving simulator were relatively weak and equivocal. They were primarily curve-specific rather than uniform across curves. No treatment was associated with consistent effects which could be interpreted as beneficial. The herringbone pattern of pavement markings exhibited consistent, but primarily detrimental effects. The flashing beacons were associated with a beneficial effect at one curve only, but exhibited stronger detrimental effects at other curves. The chevron alignment signs improved the tracking performance of drivers when sober, but increased speeds at two curves. Post

delineators were associated with beneficial effects including reductions in speed and lateral acceleration in the absence of edgelines and a tracking improvement for drivers in the sober condition.

4. The pattern of results suggests that drivers' responses to the spot treatments as implemented in the driving simulator were not consistent with previous research conducted using on-road data.

5. Several changes in performance associated with the two-hour experimental drive were observed. Increases in speed and lateral acceleration and overall performance together with increases in reaction time to signs and reaction time variability suggest a time-related shift of attention away from the discrete sign recognition task to the continuous tracking task.

6. The addition of an obstacle avoidance task to the experiment resulted in an apparent increase in alertness in the two alcohol conditions, as indicated by reduced reaction times and reaction time variabilities. These effects were not evident in the sober condition.

7. RECOMMENDATIONS

Although not conclusive, the evidence presented in this study indicates a potential benefit associated with countermeasures selected to reduce specific impairment effects. The evidence, however, is not strong enough to recommend implementation of the countermeasures tested. Follow-up research is recommended to better define this approach to accident prevention and to determine if countermeasures can be identified to address impairment effects in general, such as those associated with alcohol, fatigue, and age. Specific recommendations are now presented.

1. Additional research is needed before implementation of rumbling shoulder treatments is warranted. An experimental study using different patterns of vibration is recommended. Patterns should be designed to optimize the balance between effectiveness and implementation costs.

2. On-road observational studies are recommended to determine drivers' responses to spot treatments for curves. Results could also be used to validate the use of driving simulation for evaluation of roadway countermeasures. A critical review of recent research on the effectiveness of roadway delineation and signing techniques, including the results of the present study, is recommended.

3. Analytical studies of accident data are recommended to further existing knowledge of alcohol accident types and to determine if fatigue-related accident types can be identified.

4. Additional research and development on the potential effectiveness of in-vehicle performance monitoring and alerting devices is recommended. Despite concerns voiced by some about constraints to implementation, the availability of performance

monitoring and radar and vehicle braking technology and the apparent feasibility of on-line impairment detection indicate a potentially effective approach to accident prevention.

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