December 1984
Final Report

DOT-HS 806-649

U.S. Department of Transportation
National Highway Traffic Safety Administration

# IDENTIFICATION AND TESTING OF COUNTERMEASURES FOR SPECIFIC ALCOHOL ACCIDENT TYPES AND PROBLEMS
## VOLUME I: EXECUTIVE SUMMARY

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Contract No. DOT-HS-9-02085
Contract Amt. $423,713

## 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.

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*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.

TECHNICAL REPORT STANDARD TITLE PAGE

| | | |
|---|---|---|
| 1. Report No. DOT-HS-806-649 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle Identification and Testing of Countermeasures for Specific Alcohol Accident Types and Problems - Volume I: Executive Summary | | 5. Report Date December 1984<br>6. Performing Organization Code |
| 7. Author(s) Thomas A. Ranney and Valerie J. Gawron, Ph.D. | | 8. Performing Organization Report No. 6551-Y-1 |
| 9. Performing Organization Name and Address Calspan Field Services, Inc. 4455 Genesee Street Buffalo, New York 14225 | | 10. Work Unit No. A26<br>11. Contract or Grant No. DOT-HS-9-02085<br>13. Type of Report and Period Covered Final Report May 1979 - October 1983 |
| 12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590 | | 14. Sponsoring Agency Code |
| 15. Supplementary Notes NHTSA Contract Monitor - Marvin Levy, NRD-42<br>FHWA Contract Monitor - Richard Schwab, HSR-10 | | |

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


| | |
|---|---|
| 17. Key Words Accidents, alcohol, closed-course driving, countermeasures, curve negotiation, driving performance, driving simulator, roadway delineation, rumble strips | 18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| None | None | 34 | |

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# EXECUTIVE SUMMARY

## INTRODUCTION

The involvement of alcohol in motor-vehicle accidents is well-established. Comparisons of blood-alcohol concentrations (BACs) in crash and non-crash drivers indicate that accident risk increases with BAC. Alcohol impairment is also associated with more severe accidents, as shown by alcohol involvement ranging from approximately 16 percent of drivers in property-damage crashes to 60 percent of drivers fatally-injured. Evidence strongly indicates that impaired drivers have particularly severe accidents because of high impact speeds and the types of accidents in which they are involved. With regard to accident types, research indicates that single vehicle accidents generally involve higher proportions of drinking drivers than do multivehicle accidents. This includes road-lane departures due to loss of vehicle control and collisions with stationary targets, most often vehicles parked in the travel lane. Alcohol is also disproportionately involved in head-on collisions and to a lesser extent in rear-end collisions for drivers of the striking vehicle. Alcohol-related accidents were found to be overrepresented at night, on two-lane roads, and on curves.

In contrast, the role of alcohol involvement in heavy truck accidents is not well-understood. The available information is sparse and prone to errors in reporting alcohol-involvement. Whether alcohol use among drivers of heavy trucks is a different problem from the general driver alcohol problem is unknown; however, the relatively severe consequences of heavy truck accidents and the relatively high mileage which is typical for heavy trucks indicate a need to understand the role of alcohol in heavy truck accidents.

### Objectives and Scope of Study

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 investigate the feasibility of developing effective countermeasures directed at the identified problems.

The research was conducted in three phases. Phase I addressed the first study objective, while Phases II and III addressed the second major objective.

Phase I consisted of two research tasks, the first of which involved a review of literature and accident data pertaining to the nature and extent of the alcohol highway safety problem in general, and as related to drivers of heavy trucks in particular. Where appropriate, discussions with knowledgeable individuals were held to complement the information available from published sources.

The second task involved defining the specific alcohol-related problems in sufficient detail so that they could serve as targets for countermeasure identification. Targets included categories of location, time, vehicles, drivers, or combinations thereof, in which the drinking-driver problem is especially prominent, and which therefore have potential for making reductions in alcohol-involved accidents.

Phase II comprised three research tasks. The first task involved the identification of prospective countermeasures, based upon the collision configurations and target categories identified in Phase I. In contrast to deterrent approaches which are intended to identify and remove drinking drivers from the road, the emphasis in this study was on the development of countermeasures which reduce the consequences of alcohol-impaired driving. Focusing on the pre-crash "behavioral errors" involved in accident causation, the study considered accident-preventative rather than severity-reducing techniques. For the heavy-truck alcohol problem, deterrent or other approaches which could make use of existing Federal regulations were considered in addition to accident-specific countermeasures.

The second task in Phase II involved a preliminary evaluation of the candidate countermeasures, considering such factors as their expected effectiveness, developmental effort required for implementation, and the feasibility of empirical testing in Phase III of the study. In the third task of Phase II, procedures for empirical testing were specified for the most promising candidates.

Phase III of the study involved the empirical testing of the selected countermeasures and consisted of three major research tasks. The first task was to implement the test procedures and collect data necessary to evaluate the selected countermeasures. The second task involved reduction and analysis of the test data, while the third task involved reporting of results and conclusions concerning potential effectiveness of the tested counter-measure techniques.

## PHASE I PROBLEM DEFINITION

As indicated above, the problem definition phase of the study had two foci: (1) the general driver-alcohol problem and; (2) the heavy truck alcohol problem. Results are highlighted separately.

### Results For The General Driver-Alcohol Problem

The major collisions types associated with alcohol impairment are:

- Single vehicle crashes
- Opposite-direction, striking vehicle collisions (head-on collisions)
- Rear-end, striking vehicle collisions

Using data from accidents of all severities, the single-vehicle crash stands out as the most significant configuration associated with alcohol involvement. The other two identified accident types reflect smaller, although still above-average representations of drinking drivers, thus qualifying as "alcohol collision types."

Studies indicate that alcohol-involvement is most pronounced in crashes taking place at night. This reflects both the higher proportion of drinkers on the road at night and the increased difficulties (e.g., reduction in available information) associated with nighttime driving. Alcohol-involved accidents tend to occur more often on weekends than on weekdays.

Alcohol-related accidents have been found to be overrepresented in rural areas, on curved roads, and away from intersections. Combining the identified circumstances in which alcohol involvement was highest with the predominent collision configurations, it was found that three crash circumstances accounted for 75 percent of the accidents of alcohol-involved drivers.

- Single vehicle; midnight to 6AM; on curve -- 95 percent alcohol involvement

- Single vehicle, midnight to 6 AM; on straight section -- 83 percent alcohol involvement

- Multiple vehicle;, midnight to 6 AM -- 52 percent alcohol involvement

Based upon accident and observational studies, four basic alcohol impairment effects were identified. Experimental data were reviewed to identify convergent results pertaining to the effects of alcohol. The four effects are discussed briefly:

(1) Lowered arousal/alertness. Accident data analyses suggest that as BAC level increases, drivers' general level of alertness decreases. At high BACs, accident patterns suggest gross lapses of attention and failure to negotiate even relatively undemanding driving situations. Experimental studies support the prominence of the sedative and fear-reducing effects of alcohol which enable drivers to relax and become inattentive to the driving task.

(2) Time-sharing/Information-processing rate. Experimental evidence indicates that alcohol slows the rate of information-processing, especially in situations where performance of two or more tasks is required. Accident data, however, are generally insufficient for identifying this impairment effect.

(3) Speeding/Recklessless. Alcohol-involved accidents have been associated with higher speeds in several studies. Erratic accelerations and inappropriate speed were among a set of observable cues associated with alcohol impairment. However, whether high speed reflects intentional risk-taking or an impairment of risk perception is an open question. Laboratory studies, although criticized for removing important components of driving risk, have associated increased risk-taking with perceptual and psychomotor decrements rather than an increased acceptance of risk.

(4) Lane maintenance/Tracking Impairment. The prominence of road departures among the accidents of alcohol-impaired drivers, together with the results of experimental studies indicate that tracking impairments, especially in the time-sharing situations, are among the primary on-road effects of alcohol impairment. Drifting, swerving, weaving and other problems of lane-maintenance were prominent in one study of the observable cues associated with alcohol impairment.

## Results for the Heavy Truck-Alcohol Problem

A search of various informational sources, including individuals knowledgeable about trucking operations, revealed that rather little is available on the scope or nature of the drinking-driving problem among heavy truck operations. Studies using police reports indicate that about two percent of the accident-involved truck drivers were alcohol-impaired while studies using blood tests and small samples indicate that a quarter to a third of fatally-injured truck drivers had positive blood alcohol. Possibly the most reliable data are from the nine states where blood test rates on fatally-injured drivers exceed 80%, in the Fatal Accident Reporting System (FARS). In these data, 19 percent of the heavy truck drivers had positive BACs. Extrapolating from data across all vehicles, it is estimated that heavy truck operator alcohol involvement is approximately 8 percent in personal injury crashes and 5 percent in property damage accidents.

As to the qualitative aspects of the truck-alcohol problem, data are again extremely limited. Regarding accident types, single-vehicle accidents were found to be prominent for drinking truck drivers as they are for alcohol-involved drivers generally. Truck road departure characteristics (e.g., departure angles) suggested inattentiveness and lapse of control, entirely consistent with inferences regarding the general driver-alcohol problem. Whether any accident types are uniquely prominent for impaired heavy truck drivers cannot be said, given the paucity of data.

In lieu of data to indicate truck driving problems created by alcohol, an examination of the information-processing demands and skill requirements of heavy truck driving was made. It appears that almost any driving situation requires more attention and finer-tuned skills to maneuver a heavy truck than for an automobile. Since basic studies on alcohol impairment indicate alcohol to be especially debilitating in demanding tasks, heavy truck driving may be hypothesized to suffer more from alcohol impairment than automobile driving.

Regarding accident times, the FARS data indicate that, as in the general driver population, drinking truck drivers tend to have their (fatal) accidents at night in comparison with the non-alcohol-involved fatally-injured drivers. In comparison with drivers of other vehicles, however, the drinking truck drivers have proportionately more daytime fatal accidents. They also have proportionately more of their fatal accidents on weekdays.

With respect to accident location, the FARS data indicated that drinking truck drivers tended to have rural accidents no more than did the non-drinking drivers, but fatal truck accidents in general are proportionately more in rural areas than are fatal accidents among other drivers.

Finally, the use of alcohol by heavy truck drivers was considered with respect to the structure of the motor carrier industry. Available information suggested that willingness to combine drinking and driving is less likely among regulated drivers than those with exempt status.

## PHASE II COUNTERMEASURE IDENTIFICATION AND PRELIMINARY EVALUATION

Based upon the identified alcohol accident types and the underlying impairment effects, four general approaches to alcohol countermeasures were identified. The approaches were selected to be consistent with the stated objective of reducing the "behavioral errors" involved in accident causation. They include (1) arousing the impaired (inattentive) driver; (2) alerting the impaired driver to the existence of specific hazards; (3) providing enhanced information to the impaired driver to help simplify the driving task, and (4) providing additional skills to help compensate for alcohol-impaired driving.

With these general approaches in mind, a search of existing highway safety literature and solicitation of ideas from selected experts, led to the identification of specific candidate measures. Four categories of countermeasures are discussed briefly:

Vehicle modifications. Performance monitoring devices have been designed to monitor vehicle control inputs and alert the driver when performance falls below a pre-established criterion. Hazard warning devices use radar and sound a warning or activate the vehicle's brakes upon detection of a hazard in the vehicle's path. Improvements in vehicle rear lighting were also considered to the extent that they could improve the likelihood of detection of a lead vehicle by an impaired driver.

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). Specific sign improvements considered include improved sign messages, improved conspicuity of signs, improved placement to maximize detection likelihood, multiple signs of same message, adding flashing beacons to existing signs, and inclusion of hazard rating information on signs. Delineation treatments considered include standard and wide edgelines as well as innovative road markings such as a pattern of transverse stripes spaced to give an illusion of increasing vehicle speed.

Driver oriented countermeasures. Since deterrent countermeasures were not considered, the only driver oriented countermeasures include training either at time of initial licensing or following conviction to provide drivers with skills necessary to compensate for alcohol-impairment.

Heavy truck countermeasures. Countermeasures applicable to the heavy truck alcohol problem include enforcement of the BMCS (Bureau of Motor Carrier Safety) regulation prohibiting drinking and driving through use of breath-tests at BMCS roadside safety checks. Alternatively, detection through breath tests could be implemented at State truck weigh stations.

The candidate countermeasures were evaluated informally, using a number of criteria, including their expected effectiveness, state of development, and feasibility of testing in Phase III of the study. Specific recommendations were presented to NHTSA and FHWA. Based upon these recommendations, and upon the priorities of NHTSA and FHWA, roadway treatments were selected for evaluation in Phase III of the 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.

## PHASE III PRELIMINARY TESTING OF SELECTED ROADWAY COUNTERMEASURES

Two experiments were conducted to evaluate the potential effectiveness of the selected roadway treatments. Experiment I was a closed-course evaluation of a simulated rumbling shoulder treatment and raised centerline markers. Experiment II used a driving simulator to evaluate continuous roadway treatments (standard and wide edgelines) and spot treatments implemented in the approach to horizontal curves. The spot treatments included post delineators, chevron alignment signs, flashing beacons added to curve warning signs, and a herringbone patterned pavement marking. The procedures, results and conclusions for the two experiments are described briefly:

### Experiment I

The major question addressed was whether a patterned vibration, designed to simulate vehicle contact with a shoulder treatment (e.g., rumble strips) or with a raised lane delineator (e.g., Bott's dots) could improve the performance of subjects when sober or alcohol-dosed, on a relatively uneventful nighttime drive over a simulated rural two-lane unlighted road. A secondary question was whether the treatment effectiveness changed over time, with repeated exposure.

Methodology. A within-subjects design (Figure 1) was used.

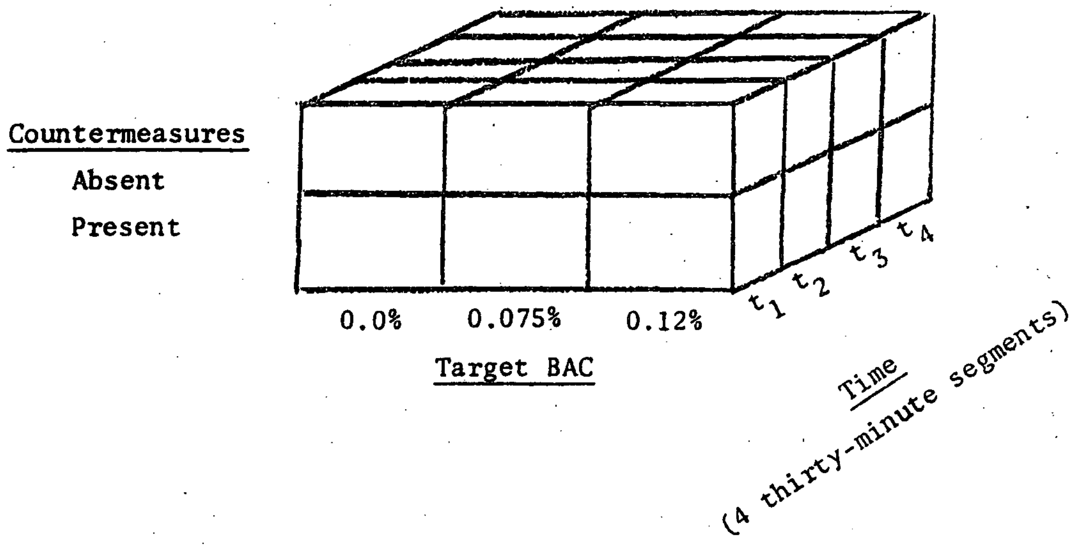


FIGURE 1. - EXPERIMENTAL DESIGN

The testing instrument was the Driver Performance Measurement and Analysis System (DPMAS), a completely instrumented 1974 Chevrolet Impala capable of onboard digital recording of driver control measures, vehicle motion variables, and driver psychophysiological measures. The vehicle was 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.

A 3.5 mile two-lane course defined by white edgelines and a yellow centerline was used. Eleven curves separated by straight segments were included in the course. Six licensed male drivers, aged 21-55 participated in the experiment. Each subject completed six experimental sessions (3 BAC levels x 2 countermeasure conditions; see Figure 1). Under nighttime conditions, the subjects were instructed to complete 20 laps of test course, maintaining a constant speed (40 mph) except on curves, and keeping in the right-hand lane in anticipation of oncoming traffic. In the countermeasure-absent condition, the drive was uninterrupted except at 30-minute intervals, when the subject was instructed to change the direction of travel. In the countermeasure-present condition, deviations from the travel lane, when observed by the experimenter, resulted in activation of the countermeasure mechanism, causing vehicle vibration. Right-side excursions resulted in continuous vibrations to simulate a shoulder treatment. Vehicle vibration continued until the wheels returned to the travel lane. Left-side departures resulted in a vibration of short duration to simulate vehicle contact with a single raised delineator on the centerline (with 40-foot spacing).

The data collected included the frequency and characteristics of lane deviations and measures of vehicle control sampled each lap at a selected straight and curved road segment.

<u>Results</u>. Due to recurrent inclement weather and problems with the data recording equipment, a significant portion of the data was lost. To compensate for this problem, a very conservative statistical model was chosen for data analysis. ANOVAs were run for each dependent variable using the following main factors: BAC (0.0%, 0.07%, 0.12%); Countermeasure (Absent, Present); Time (four 30-minute segments). The GLM procedure of SAS used estimates of missing data to calculate F values in the ANOVAs.

The effects of alcohol are summarized in Table 1. Of all the factors in the experiment, the effects of alcohol were strongest and most consistent. The frequency (per 30-minute segment) of both left and right lane deviations increased significantly with alcohol. The time between successive same-side deviations decreased significantly in the alcohol-conditions. However, among the categories of measures considered, the characteristics of lane deviations, including the maximum lateral distance outside the travel lane and the time (seconds) outside the travel lane, were least influenced by alcohol. Of these measures, only the time outside the travel lane for left deviations was significantly longer at the high BAC (0.12%) condition than at the sober (0.0%) condition.

TABLE 1. - SUMMARY OF ALCOHOL EFFECTS (EXPERIMENT I)

| Measure | Alcohol Effect | Interpretation |
|---|---|---|
| Lane deviation frequency: | | |
| left | Yes | increase at high BAC[1] |
| right | Yes | progressive increase with BAC[2] |
| 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[3] |
| 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 |

[1] Increases or decreases indicate differences determined through post hoc analyses to be significantly different from the sober (0.00%) condition.

[2] All means are different.

[3] Both BAC conditions are different from the sober condition, but not different from each other.

Four measures of general driving behavior (mean velocity, standard deviation of velocity, mean lateral position, standard deviation of lateral position) were examined. Separate ANOVAs were computed for straight and curved road segments. Alcohol effects were significant on six of the eight ANOVAs. The two measures of variability increased with BAC. Mean velocity on the curved road exhibited an increase at the high BAC condition indicating a failure to reduce speed for curve negotiation. The alcohol effect on lateral position was significant only on the curved road segment.

The effects of the countermeasure treatments are summarized in Table 2. In contrast to the relatively consistent effects of alcohol, the countermeasure effects were not as strong. Countermeasure presence was found to decrease the frequency of left deviations for drivers in the high BAC condition, and to increase the time between successive left deviations. Neither effect was statistically reliable.

On both the curved and straight road sections, the countermeasure presence was associated with a significant overall increase in mean velocity. The effects, however, differed according to BAC level. Whereas mean speed increased at BAC1 (0.00%) and BAC3 (0.12%), it was observed to decrease at BAC2 (0.07%). On the straight road segment, subjects were observed to move closer to the centerline in the countermeasure-present condition. While the effect of the treatment on speed variability was not significant, the variability of lateral position on curves was reduced in the presence of the countermeasures. A similar, but nonsignificant, effect was observed on the straight road section.

Performance decrements associated with driving time were interpreted as fatigue effects. Interactions of time segment with BAC were interpreted as fatigue-alcohol interactions. In general, fatigue effects were not nearly as evident or strong as effects of alcohol. The frequency of right side lane deviations increased over time, while the time between successive left side deviations decreased. The latter effect was not statistically reliable. The mean straight road velocity decreased over time for all BAC conditions, while curved-road velocity decreased over time for drivers in the BAC1 (0.00%) and BAC2 (0.07%) conditions. The variability of velocity on the curved road was found to increase with time and the lateral position variability was found to

TABLE 2. - SUMMARY OF COUNTERMEASURE EFFECTS (EXPERIMENT I)

| 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<br>Significant increase at BAC3<br>Significant decrease at BAC2 |
| | Straight | Yes | Significant overall increase<br>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<br>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.

decrease over time, but only for drivers in the sober condition. Other effects of time segment reflected differences attributable to the direction of travel on the test course, which alternated between time segments.

## Experiment II

Using the driving simulator at Systems Technology, Inc. (STI), a second experiment was conducted to evaluate the effects of selected roadway treatments on the performance of subjects under sober and alcohol dosed conditions. The treatments evaluated included:

(1) Continuous treatments

- Standard edgelines (4 inch)
- Wide edgelines (8 inch)

(2) Spot treatments at curves

- Herringbone patterned pavement markings
- Flashing beacons on curve warning signs
- Chevron alignment signs
- Post delineators

Methodology. A within-subjects design was used. Twelve subjects, aged 21-55, attended six experimental sessions, as shown in Figure 2. The target BACs (0.00%, 0.07%, 0.12%) were selected to be consistent with the closed-course experiment. 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 added the requirement that drivers respond to unexpected obstacles in addition to curves and signs. Both scenarios required subjects to drive continuously for two hours.

| Attentional Demand | Target BAC: 0.00% | 0.07% | 0.12% |
|---|---|---|---|
| Uneventful | | | |
| Eventful | | | |

FIGURE 2. - BETWEEN SESSION EXPERIMENTAL DESIGN

The within-session experimental design is shown in Figure 3. This block corresponds to a single one-hour block of the driving scenario timeline (Figure 4). Each edgeline layer of Figure 3 corresponds to a 20-minute segment in Figure 4. 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. During each two hour drive, each subject negotiated 150 (6 segments x 5 curve types x 5 spot treatments) curves. 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.

The STI car simulator is a completely instrumented cab resting on a fixed base. 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. These equations then drive the cab instruments and interactive display generator which presents road delineation cues via a CRT display. 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. One slide image consists of a sign projected through a zoom lens. The other image is a fixed size horizon scene which provides a visual texture background for the sign images.

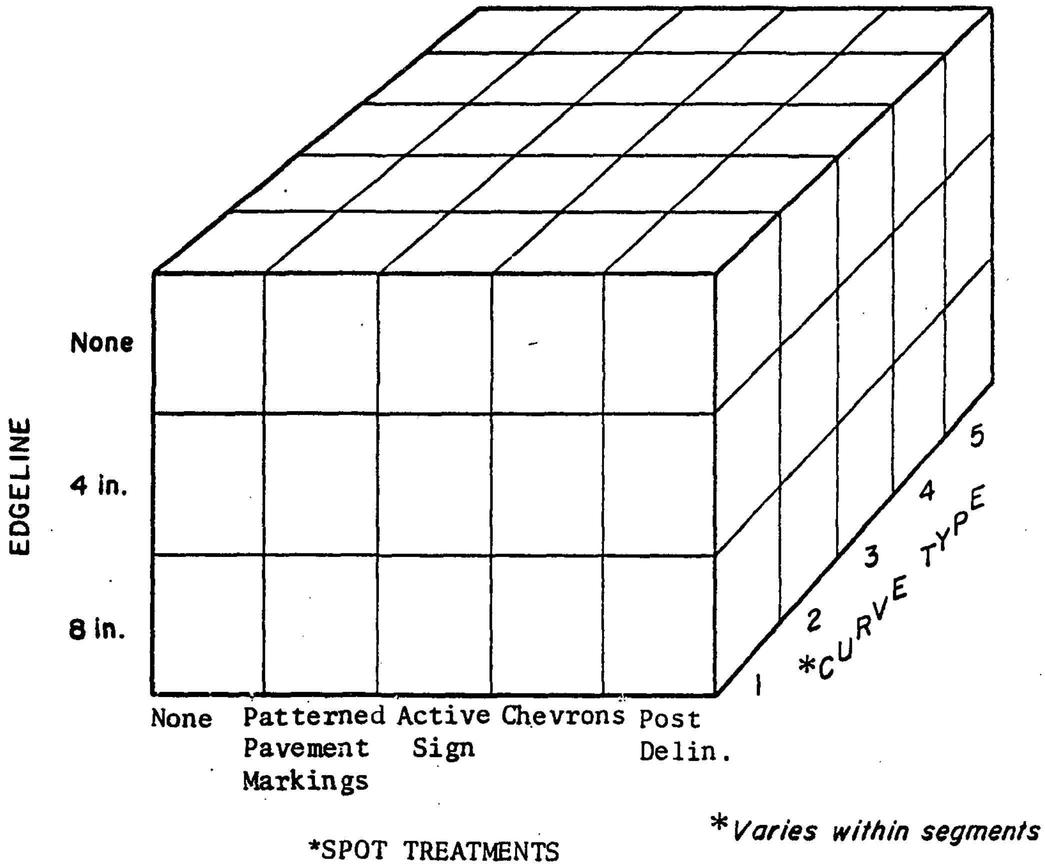


FIGURE 3. - WITHIN SESSION EXPERIMENTAL DESIGN

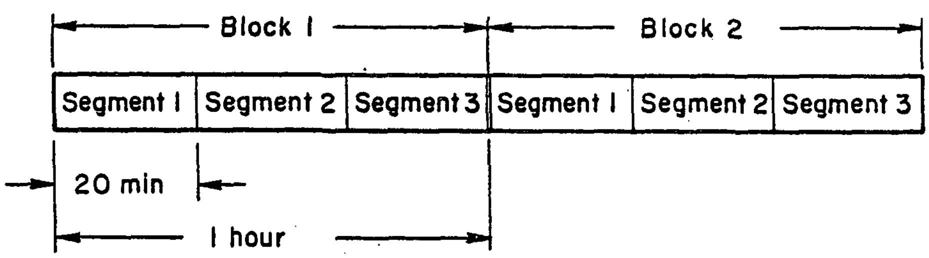


FIGURE 4. - DRIVING SCENARIO TIMELINE

The edgeline treatments, post delineators, and 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.

Table 3 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.

Results. Separate ANOVAs were conducted for each dependent variable. With the exception of the measures in Category 4 (Table 3), the independent variables for each analysis were the same: subject (12); attentional demand (High, Low); BAC (0.0%, 0.07%, 0.12%); Hour (1, 2); Edgeline width (0, 4, 8) inches; curve (5); and spot treatment (5). Analysis of Category 4 measures eliminated curve and spot treatment as factors.

The effects of alcohol are summarized in Table 4. The effects of alcohol were most evident in the six segment summary measures (Category 4), of which three exhibited significant alcohol effects. It was found that subjects struck more obstacles in the high BAC condition than in the sober or low BAC conditions. The number of speed limit exceedances increased significantly with BAC and the pay (monetary reward) was significantly less at the high BAC condition than at the other two conditions.

TABLE 3. - DRIVER PERFORMANCE MEASURES FROM STI SIMULATOR

| Data Category | Collection Location | Variables | Number of Samples |
|---|---|---|---|
| 1 | Curve approach and transition | speed<br>lateral position<br>heading error* | 8 spot measures at 100 foot intervals |
| 2 | Fixed portion of curve | lateral position (1 foot intervals)<br>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<br>number of speed exceedances<br>pay | number of occurrences in each 20 minute segment |
| | b. Summary Scores | time to complete segment | summary score for each 20 minute segment |
| | c. Reaction Time (RT) | sign detection reaction time<br>standard deviation of reaction time | mean for each 20 minute segment |

*actual path relative to ideal path

TABLE 4. - SUMMARY OF ALCOHOL EFFECTS (EXPERIMENT II)

| Measure | Category | Alcohol Effect | Interpretation |
|---|---|---|---|
| Curve entry speed | Curve approach | No | |
| Total lane position error | Curve approach | Yes | Increase from B1 to B3 |
| Total heading error | Curve approach | Yes | Effect at B3 only[1] |
| Mean lateral acceleration | Curve negotiation | No | |
| Amount of road used[3] | Curve negotiation | Yes | Effect at B3 only |
| Number obstacles struck | Segment measure | Yes | Effect at B3 only |
| Number of speed exceedances | Segment measure | Yes | Progressive increase[2] |
| 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.

[3] Amount of road used was derived from lateral position in curve negotiation.

B1 = BAC (0.00%)
B2 = BAC (0.07%)
B3 = BAC (0.12%)

In the approach to horizontal curves, alcohol had no effect on curve entry speed. Alcohol did increase both the total lane position (deviation from the center of the lane) and also the total heading error (the heading of the vehicle relative to the path of the road). In curve negotiation, alcohol had no effect on the lateral acceleration, but did increase the amount of road used.

The effects of edgeline width are summarized in Table 5. When observed, the effects were attributable to edgeline presence rather than width. In the curve approach, edgeline presence increased curve entry speed, but had no effect on the total lane position or heading error. Edgeline presence influenced both measures of curve negotiation. Increased lateral acceleration and decreased amount of road used were associated with edgeline presence. The latter effect was attributable to two of the five curve types. Of the six segment summary measures, edgeline presence exhibited a significant effect on two (pay and time to complete segment). Edgeline presence increased pay, indicating an improvement in overall driving performance, while at the same time decreasing time to complete a segment, indicating an overall increase in driving speed.

Three of the dependent measures exhibited reliable alcohol and edgeline effects, thus allowing a comparison of the magnitude of the effects. For all three measures, the magnitudes of the alcohol-related performance decrements were greater than the improvements associated with the edgeline conditions. Table 6 compares the magnitude of the effects. For each of the three measures, the largest performance decrement, associated with the sober versus high BAC condition difference, was compared to the standard and wide edgeline effects.

TABLE 5. - SUMMARY OF EDGELINE EFFECTS IN STI SIMULATOR

| Measure | Category | Edgeline Effect[1] | 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 (ExC) | Edgeline presence amount of road used at 2 curves only. No additional wide edgeline effect. |
| Number of obstacles struck | Segment summary | No | |
| Number of speed exceedances | Segment summary | No (HxE) | In second hour, 4" (E2) condition increased number of speed exceedances. |
| 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 | |

[1]Yes indicates significant main effect. Significant interactions are indicated parenthetically (E=Edgeline, C=Curve, H=Hour)

TABLE 6. - COMPARISON OF ALCOHOL AND EDGELINE EFFECTS

| Measure | Alcohol Effect | Edgeline Effect | % Reduction Alcohol Eff. | 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

The edgeline conditions were associated with benefits of between 30 and 46 percent of the performance decrement associated with the B3 (0.12%) 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 spot treatment effects are summarized in Table 7. In general the effects were not strong, as indicated by the general absence of treatment main effects. For example, a significant curve entry speed reduction was associated with the herringbone pavement markings, but the effect was only evident at two of the five curves. The post delineators were also associated with reduced curve entry speeds, but only at two curves, and only in the absence of edgelines.

TABLE 7. - 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<br>BxT | Increase in lane position error at B1, B2, but not at B3 |
| | Heading error | T | Increase in heading error |
| | Lateral acceleration | T<br>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<br>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<br>ExT | Speed reduction at 2 curves only. Speed reduction in absence of edgelines only |
| | Amount of road used | CxT<br>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).

BAC x treatment interactions indicate different effects for different BAC levels. For example, the herringbone pattern was associated with an increase in total lane position error, but only at the sober and low BAC conditions. Both the Chevron alignment signs and post delineators were associated with a decrease in the amount of road used in the negotiation of one curve, but only when subjects were at the no BAC (sober) condition.

Two treatments, the herringbone pattern and post delineators were associated with reduced lateral acceleration, but only in the absence of edgelines.

The effects of time are summarized in Table 8. A general improvement in driving in the second hour is indicated by an increase in pay. Overall speed (from time to complete segment) increased in the second hour, while the curve entry speeds and lateral accelerations associated with curve negotiation also increased. None of the lateral position (tracking) measures exhibited time-related changes. Reaction time to signs and reaction time variability increased in the second hour, relative to the first hour. None of the effects of either edgelines or spot treatments exhibited reliable changes over time.

The effects of task demand (uneventful versus eventful scenario) were also examined. None of the curve approach and negotiation variables exhibited main effects of demand. One segment summary measure (RT to signs) exhibited a significant main effect of demand, reflecting faster RTs in the eventful (included obstacle avoidance) scenario. Countermeasure effects did not change according to the level of task demand.

TABLE 8. - SUMMARY OF TIME EFFECTS IN STI SIMULATOR

| Measure | Category | Time Effect | 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 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 |

## SUMMARY AND CONCLUSIONS

### 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 missing or unreliable, 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.

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 30-40 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. 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.

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