DRIVER INATTENTION AND HIGHWAY SAFETY

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ABSTRACT

The Transportation Systems Center, in support of research carried out by the National Highway Traffic Safety Administration's Crash Avoidance Division, has reviewed research into driver attentional processes to assess the potential for the development of methods and techniques for reducing accidents related to attentional lapses. This paper summarizes the results of the review with regard to the safety implications of inattention, psychological and physiological indices of inattention, and in-vehicle instrumentation for detecting inattention. This paper concludes by suggesting areas of research which could be valuable in the development of practical attention monitors for in-vehicle use.

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1.0 INTRODUCTION

The Transportation Systems Center, in support of research carried out by the National Highway Traffic Safety Administration's Crash Avoidance Division, recently completed a review of driver attentional processes. This paper summarizes the results of the review.

Lapses in driver attention have been identified as a significant contributing factor in as many as 90 percent of traffic accidents. In light of this fact, an effort was conducted to determine the potential value of developing a system to monitor driver attention. This effort consisted of a review of the state-of-the-art of research into driver attentional processes, analysis of the 1982 National Accident Sampling System (NASS) data, and investigation of the current technology available for sensing degradations in driver alertness. The material in this paper is abstracted from a report prepared for NHTSA's Crash Avoidance Division entitled, "Potential for Driver Attention Monitoring System Development." The report is currently in press.

The status of research into driver attentional processes has remained fairly constant since Shinar et al. documented their review of the concepts of attention in 1978. More recent research has confirmed the general conclusions drawn by the studies reviewed by Shinar et al., as well as reiterating the complexity of driver attentional processes. It was apparent from reviewing the available data that combining indicators of attentional state with indicators of the driving environment could significantly improve the accuracy of driver attention monitoring.

NHTSA's accident data base is a valuable resource for estimating the impact of driver attention on highway safety. The 1982 NASS data was analyzed to develop hypotheses on the influence of driver inattention on traffic accidents. The 1982 data was selected because it is the first file that emphasized driver related factors in crash avoidance. The data showed that in accidents where an avoidance manuever might have been of value a large portion (37 percent) of the drivers involved took no action to avoid the collision. This supports the hypothesis that attentional lapses are a major factor in highway accidents. Another possibly very large portion of drivers did not take action until it was too late to avoid the accident. It is suspected that driver inattention played a major role in these accidents as well.

Several devices have been developed over the years to monitor driver alertness and to stimulate the driver when a degradation in performance occurs due to inattention or drowsiness. A number of these devices are currently commercially available. These devices range from a simple "head-droop" alarm to a microprocessor-based monitor of steering wheel motion, driving-pattern, and time-patterns fully integrated into an automoblile system as original equipment. Both physiological and behavioral inattention indicators were investigated with respect to the technology of sensing the indicator and relative advantages/disadvantages of each as a practical monitor of inattention.

1.1 BACKGROUND

To a large extent, the safe operation of any system requiring direct human control depends on the level of attention that the human controller provides. In the case of motor vehicle operation, the driver must sample the driving environment, select the critical aspects of the environment, determine the proper response(s), make the response(s), and evaluate the outcome(s) of the response(s). To the extent that the driver does not sample the environment with sufficient frequency, does not select the appropriate stimuli, or does not respond in a timely manner, safety will be diminished.

Available driver inattention countermeasures include work-rest scheduling, educational campaigns, use of chemical stimulants, and the detection of degraded alertness (as inferred from changes in performance) through the use of sensor systems. In industrial and military settings, the alleviation of alertness-related safety problems generally is handled through the establishment and enforcement of duty schedules. The establishment and enforcement of work-rest schedules is not a practical countermeasure for dealing with the vast majority of road vehicle accidents, because they involve either private automobiles or owner-operated trucks. Educational and public information campaigns range from "defensive driving" courses to public service announcements before national holidays. Perhaps the most popular countermeasure is the use of legal and illegal chemical stimulants (particularly caffeine) to improve alertness.

ATTENTIONAL PROBLEMS

As Shinar, Zaidel, and Paarlberg (1978) noted in their comprehensive review, lapses in driver attention can be assumed to be a significant contributory factor in traffic accidents. They cite estimates from 15 to 90 percent as the proportion of traffic accidents related to inattention. This great range can, to a large extent, be attributed to differences in definitions of attention-related problems.

For the purpose of examining the impact of such failures on driving safety, it is valuable to consider physical and psychological states which are likely to degrade alertness and to describe their impact on driving performance:

- <u>Drowsiness</u>: Except in cases where there is a known organic cause, such as narcolepsy, drowsiness can be attributed to a lack of sleep or a disturbance to the sleep-rest cycle (dysynchronosis). There are complex hypotheses which explain the need for periodic sleep and dreaming. These relate to the diurnal hormonally regulated rhythms which cause the periodicity of sleep and the need for a reorganization of information acquired during waking hours, respectively. Whatever the causes of the need for sleep and concomitant dreaming, it is clear that "sleep deprivation leads to increased performance degradation as a result of an increase in the frequency of automatic periods of light sleep during enforced wakefulness and a heightening of the threshold of stimulation required to keep the individual from falling asleep" (Coffer and Apply, 1964). It is the occurrence of the light micro-sleeps which is a problem in highway safety. During these micro-sleeps, the driver neither attends nor responds to the driving environment.

- Physical fatigue: This can be a result of continued physical exertion or exposure to environmental stresses such as temperature and humidity extremes, excessive acoustic noise levels, and severe physical vibration. Physical fatigue is likely to result in distraction or an increased concern with internal stimuli and a concomitant decrease in attention to external stimuli. This change in focus from external to internal stimuli can be hypothesized to result in the missing of critical signals by the driver. Further, fatigue can result in decreased response accuracy by the driver. This can cause a greater number of responses to be required to achieve a desired maneuver, which will further distract the driver from concentrating on external events. Physical fatigue is often a problem in military and industrial settings. It is less likely to be a problem for passenger car drivers than for the operators of heavy trucks who are often subjected to very high noise and vibration levels.

- Excess mental workload: Here the driver has too many stimuli to attend to or too many responses to make in a limited amount of time. Skilled drivers learn to handle this situation by restricting their attention monitoring to the most critical inputs and meeting only the most critical control requirements. Less skilled drivers may choose to monitor inappropriate inputs or to make noncritical responses. Some drivers may go into "saturation" and make no response, or "freeze".

- Intoxication due to alcohol, drugs, or other chemicals: Reductions in alertness are a direct or side effect of the use and/or abuse of a large number of substances. The exposure to pollutants, chief among them carbon monoxide, produces drowsiness, unconsciousness and eventual death. The effects of the ingestion of illegal drugs and legal medications vary as widely as do their chemical formulae, ranging from depression and drowsiness through agitation to hallucination. Although alcohol abuse by motor vehicle operators is perhaps the single greatest cause of traumatic injury in the U.S. today, there is still considerable debate with regard to the particular behavioral changes caused by alcohol ingestion that result in dangerous driving practices.

- Simple inattention: In this case the driver either is not attending to any stimuli or is not attending to the proper external stimuli. This behavior can be described as "daydreaming," "woolgathering" or any of a number of colloquial terms. This inattention may be the result of any or all of the above-described problems, or may simply result from introspective behavior by the driver or a distraction of the driver. The operational result is that the driver makes a delayed response, an inappropriate response, or no response at all.

While the above-described conditions have a wide range of physiological concomitants, they have one particular behavioral similarity: **in a non-alert state, the driver is less likely to respond in a timely and appropriate fashion to his or her environment than in the alert state.**

In a laboratory setting with a controlled environment, the reduction in response frequency and appropriateness can be readily measured. The challenge is to discriminate accurately and reliably between changes in reponses due to driver alertness and those changes imposed by driving conditions in the real world. This paper describes an attempt to assess the near-term feasibility of driver alertness measurement.

2.0 ACCIDENT STATISTICS

2.1 ACCIDENT DESCRIPTIONS

To develop hypotheses about to the impact of driver inattention on traffic accidents, data was obtained from the National Accident Sampling System (NASS) files. The 1982 NASS was chosen because it is the first file to provide detailed information on the driver's role in traffic accidents. Data from a particular subset of accidents was selected to investigate inattention. This data came from "reportable accidents" where the vehicles involved were moving and the role of the drivers involved had been recorded. The following factors were used in analyzing the file:

2.2.2 DROWSY

Figure 2 represents breakdowns of the frequency of all "collision" accidents where the driver was judged to be **"drowsy"**, the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included), and the vehicle was in motion. In the 1982 NASS file, 176 or more than 1% of all collisions involved vehicles in accidents that met these criteria. It should be noted that the accidents examined represent a large range in terms of severity. They range from "minimum reportable" to "multiple fatality." In this broad range of accidents alcohol does not play as large a role as it does in very severe accidents. The impact of alcohol increases dramatically with severity. In the most serious accidents, alcohol is implicated as a factor in about 50 percent of the cases. In the broad range of accidents analyzed for this study:

- o 104 or 59% were "striking" vehicles whose driver took no avoidance action prior to the collision;
- o 4 or 2% were "struck" vehicles whose driver took no avoidance action prior to the collision;
- o 66 or 37% were "striking" vehicles whose driver took avoidance action prior to the collision; and
- o 2 or less than 1% were "struck" vehicles whose driver took avoidance action prior to the collision.

2.2.3 DRUNK

Figure 3 represents breakdowns of the frequency of all "collision" accidents where the driver had a blood alcohol level in excess of 0.07 %, the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included), and the vehicle was in motion. In the 1982 NASS file 376 or 3% of all collision-involved vehicles in accidents meet these criteria. In these accidents:

- o 157 or 42% were "striking" vehicles whose driver took no avoidance action prior to the collision;

- 11 or 3% were "struck" vehicles whose driver took no avoidance action prior to the collision;
- 195 or 51% were "striking" vehicles whose driver took avoidance action prior to the collision; and
- and 13 or 3% were "struck" vehicles whose driver took avoidance action prior to the collision.

2.2.4 MEDICATION - LEGAL AND ILLEGAL

Drivers involved in accidents meeting the above mentioned collision criteria who were found to have used legal or illegal drugs prior to collision, respectively, represent less than 0.1% of the cases meeting the collision definition.

2.2.5 DRIVER AGE

Table 1 and Figure 4 depict driver responses in accidents attributable to inattention versus driver age. The data indicate that younger drivers were more inclined to make avoidance maneuvers than older drivers. The relationship between failure to respond in a collision type accident and age appears to be linear. As would be expected, the the number of cases where the driver fails to respond is greater in accidents where the driver's vehicle is "struck" than when it is the "striking" vehicle.

2.2.6 TIME OF DAY

Table 2 distributes accidents due to inattention by time of day. Between the hours of 6:00 AM and 4:00 PM (AM Rush to Mid-Day), a higher percentage of drivers took no action to avoid an accident. After 4:00 PM, drivers were more inclined to attempt an avoidance action.

2.3 SUMMARY

Thus, in all collision accidents in which the vehicles were under way and a driver response conceivably might have avoided the collision or lessened the severity of the collision (11868 accidents), the NASS investigators found:

changes caused by alcohol ingestion that result in dangerous driving practices.

- <u>Simple inattention</u>: In this case the driver either is not attending to any stimuli or is not attending to the proper external stimuli. This behavior can be described as "daydreaming," "woolgathering" or any of a number of colloquial terms. This inattention may be the result of any or all of the above-described problems, or may simply result from introspective behavior by the driver or a distraction of the driver. The operational result is that the driver makes a delayed response, an inappropriate response, or no response at all.

While the above-described conditions have a wide range of physiological concomitants, they have one particular behavioral similarity: **in a non-alert state, the driver is less likely to respond in a timely and appropriate fashion to his or her environment than in the alert state.**

In a laboratory setting with a controlled environment, the reduction in response frequency and appropriateness can be readily measured. The challenge is to discriminate accurately and reliably between changes in reponses due to driver alertness and those changes imposed by driving conditions in the real world. This paper describes an attempt to assess the near-term feasibility of driver alertness measurement.

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2.1.1 VEHICLE FACTORS

- Vehicle Role: Striking/Struck and Single Vehicle Accidents
  Striking and struck were extracted to eliminate vehicles involved in chain reaction accidents (both striking and struck). Driver attention clearly is more important with regard to the role of the driver in the striking vehicle. However, in some cases, if the driver of the struck vehicle properly responds in a pre-accident situation, the accident can be avoided or the severity of impact reduced. To reduce the ambiguity with regard to the role of the struck vehicle's driver, only cases where the vehicles were in motion were considered (see Vehicle Speed, below).

  Based on the NASS definitions of vehicle role, single vehicle accidents are included in the striking/struck categories. Both a vehicle striking another vehicle and a vehicle striking a roadside object are classified as striking vehicles. A struck vehicle in a single vehicle accident would have been hit by something other than another vehicle, such as a pedestrian or some form of debris.

- Vehicle Speed: Only cases where vehicles had speeds greater than 0.5 mph prior to the accident were considered because it was assumed that driver response was likely to be critical only when his or her vehicle was moving.

2.1.2 DRIVER FACTORS

- Attempted Avoidance Maneuver: Two levels were examined: cases where no avoidance maneuver occurred and cases where any avoidance maneuver occurred.

- Driver Drowsy: This driver factor reflects cases where the driver's being drowsy, asleep, or fatigued was considered a cause of the accident.

- Driver Drugs-Medication: This factor reflects cases where the use of "legal" drugs was considered to be the cause of the accident.

- Driver Other Drugs: In these accidents, the cause was attributed to the driver's use of illegal drugs.

- Driver Inattention: In these accidents, the cause was attributed to the driver's lack of attention.

- Alcohol Abuse: In these cases, the measured blood alcohol level of the driver was in excess of 0.07 percent.

- Age of Driver: Drivers were grouped by age: from 20 to 70 years old in five year intervals.

2.1.3 ACCIDENT FACTORS

- Land Use: Land use groups the accidents in terms of urban or rural sites.

- Time Period: The day was divided into five time periods: Early AM (accidents that occurred between the hours of midnight and 5:59 AM), AM Rush (all accidents that occurred between 6:00 AM and 9:59 AM), Mid Day (10:00 AM to 3:59 PM), PM Rush (4:00 PM to 6:59 PM), and Evening (7:00 PM to Midnight).

- Road Alignment: The data was grouped into accidents that occurred on curved sections of roadway and those that occurred on straight sections of roadway.

- Number of Occupants: The data was examined to determine the influence of the presence of passengers in a vehicle (greater than one) on the accident. Vehicles having the driver as the only occupant are designated as occupant equal to one.

- Day of Week: The week was divided into weekdays (Monday through Friday) and weekends.

The NASS file provides a number of methods for estimating the role of attentional factors in crash avoidance. For the purposes of this document, the NASS file output was structured to examine the relationship between the above listed driver factors and crash frequency.

While the report this paper is abstracted from deals with all of the factors listed, perhaps the most suggestive information comes from considering the vehicle role.

2.2 1982 NASS DATA

2.2.1 FAILURE TO MAKE A PRE-COLLISION RESPONSE

The broad operational definition of driver inattention used in this paper is: **the attentional state where the driver fails to respond to a critical situation.** Figure 1 shows the frequency of all "collision" accidents where the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included) and the vehicles were in motion. In the 1982 NASS file there are 11,868 vehicles involved in accidents that meet these criteria. In these accidents:

- 2,665 (or 22 percent) were "striking" vehicles whose driver took no avoidance action prior to the collision;

- 1,838 (or 15 percent) were "struck" vehicles whose driver took no avoidance action prior to the collision;

- 5,916 (or 50 percent) were "striking" vehicles whose driver took avoidance action prior to the collision; and

- 1449 (or 12 percent) were struck vehicles whose drivers took avoidance action prior to the collision.

DRIVER RESPONSES IN ALL
COLLISION ACCIDENTS

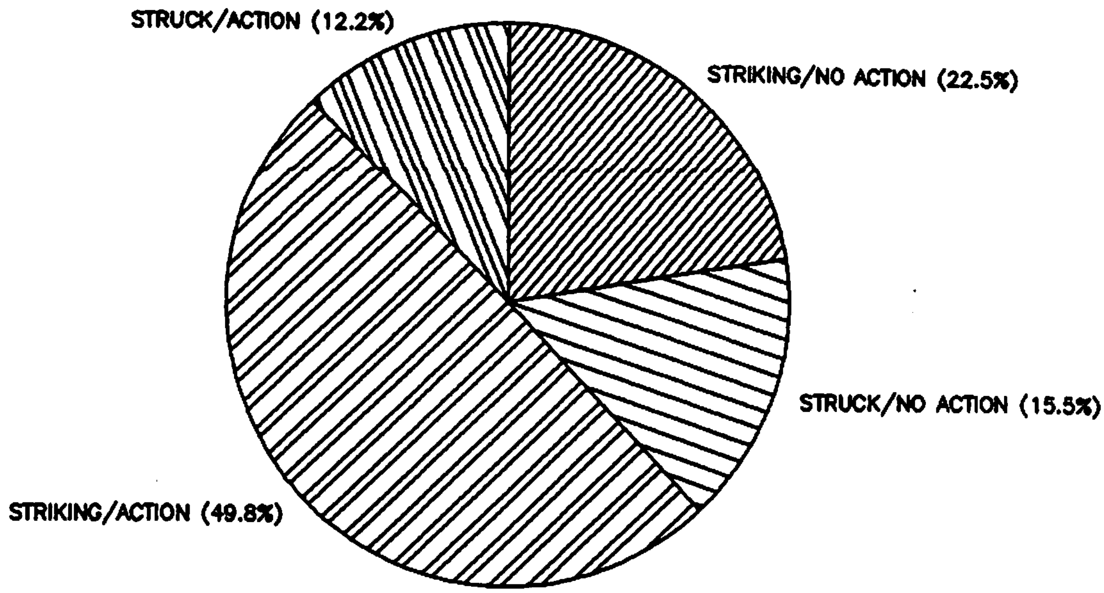
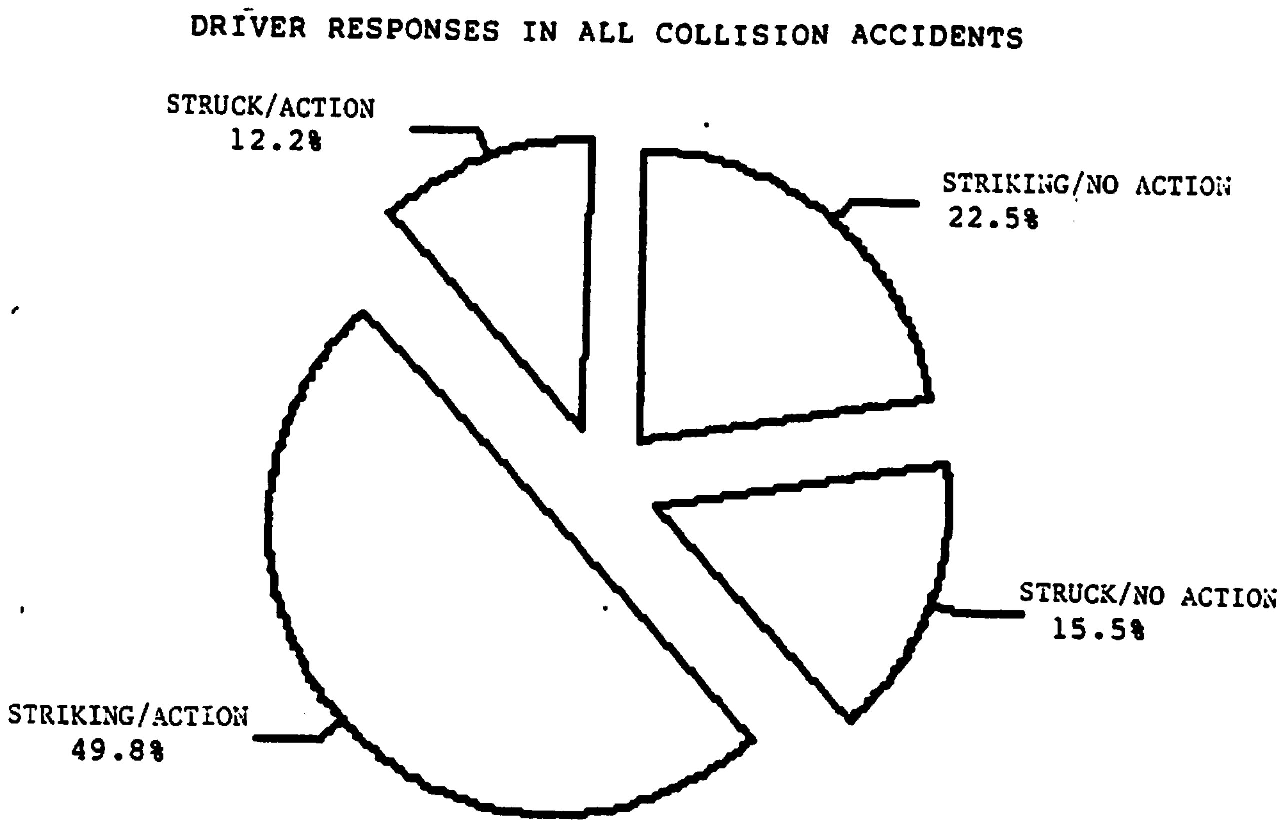


FIGURE 1


DRIVER RESPONSES IN ALL COLLISION ACCIDENTS
STRUCK/ACTION
12.2%
STRIKING/NO ACTION
22.5%
STRUCK/NO ACTION
15.5%
STRIKING/ACTION
49.8%

2.2.2 DROWSY

Figure 2 represents breakdowns of the frequency of all "collision" accidents where the driver was judged to be **"drowsy"**, the role of the vehicle was known to be either striking or struck (vehicles whose roles were unknown or were involved in chain reaction collisions were not included), and the vehicle was in motion. In the 1982 NASS file, 176 or more than 1% of all collisions involved vehicles in accidents that met these criteria. In these accidents:

- 104 or 59% were "striking" vehicles whose driver took no avoidance action prior to the collision;
- 4 or 2% were "struck" vehicles whose driver took no avoidance action prior to the collision;
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- 157 or 42% were "striking" vehicles whose driver took no avoidance action prior to the collision;
- 11 or 3% were "struck" vehicles whose driver took no avoidance action prior to the collision;
- 195 or 51% were "striking" vehicles whose driver took avoidance action prior to the collision; and

ACCIDENTS ATTRIBUTABLE TO DROWSINESS

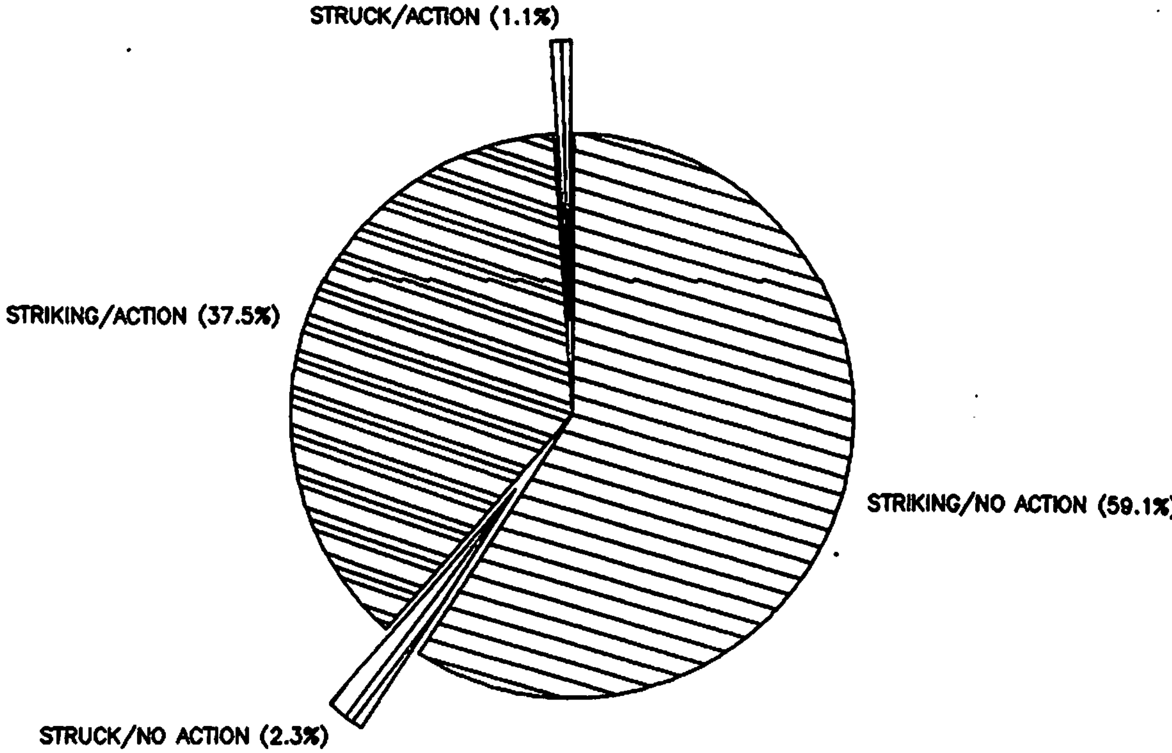
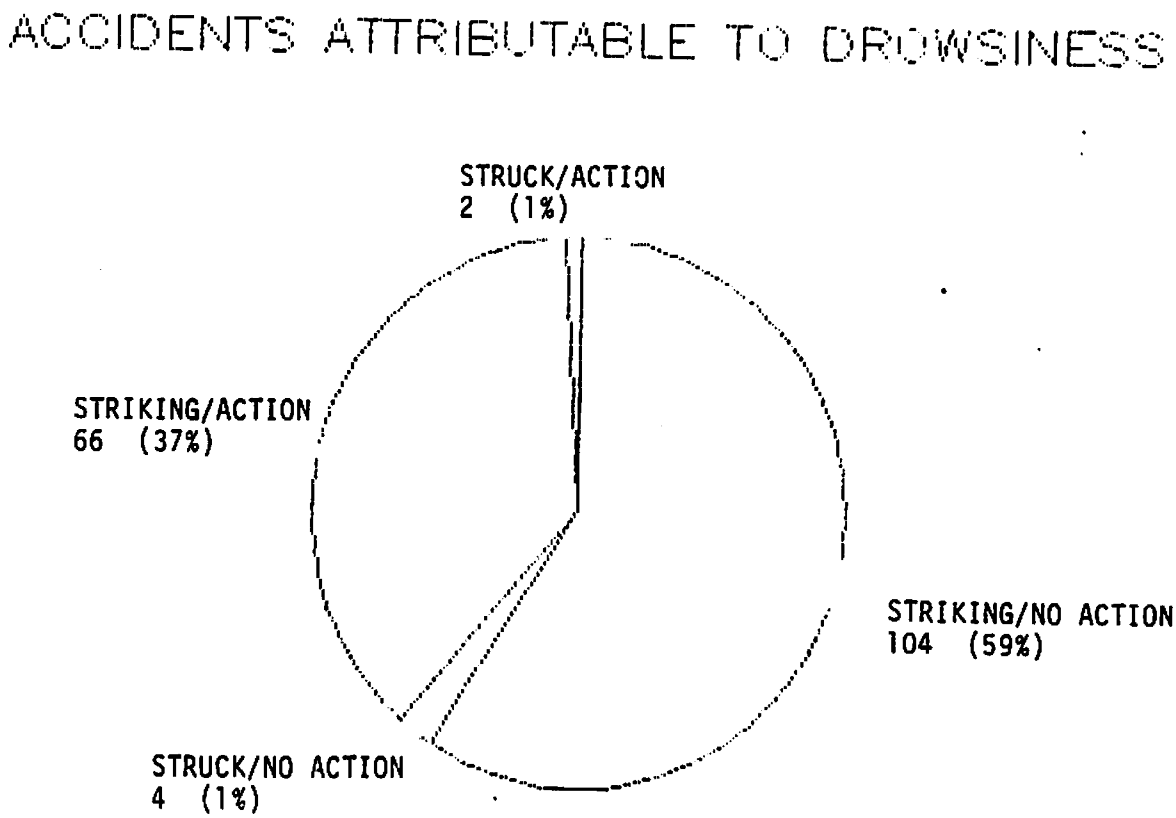


FIGURE 2


ACCIDENTS ATTRIBUTABLE TO DROWSINESS
STRUCK/ACTION
2 (1%)
STRIKING/ACTION
66 (37%)
STRIKING/NO ACTION
104 (59%)
STRUCK/NO ACTION
4 (1%)

ACCIDENTS ATTRIBUTABLE TO DRUNK DRIVERS

(BAC>.07%)

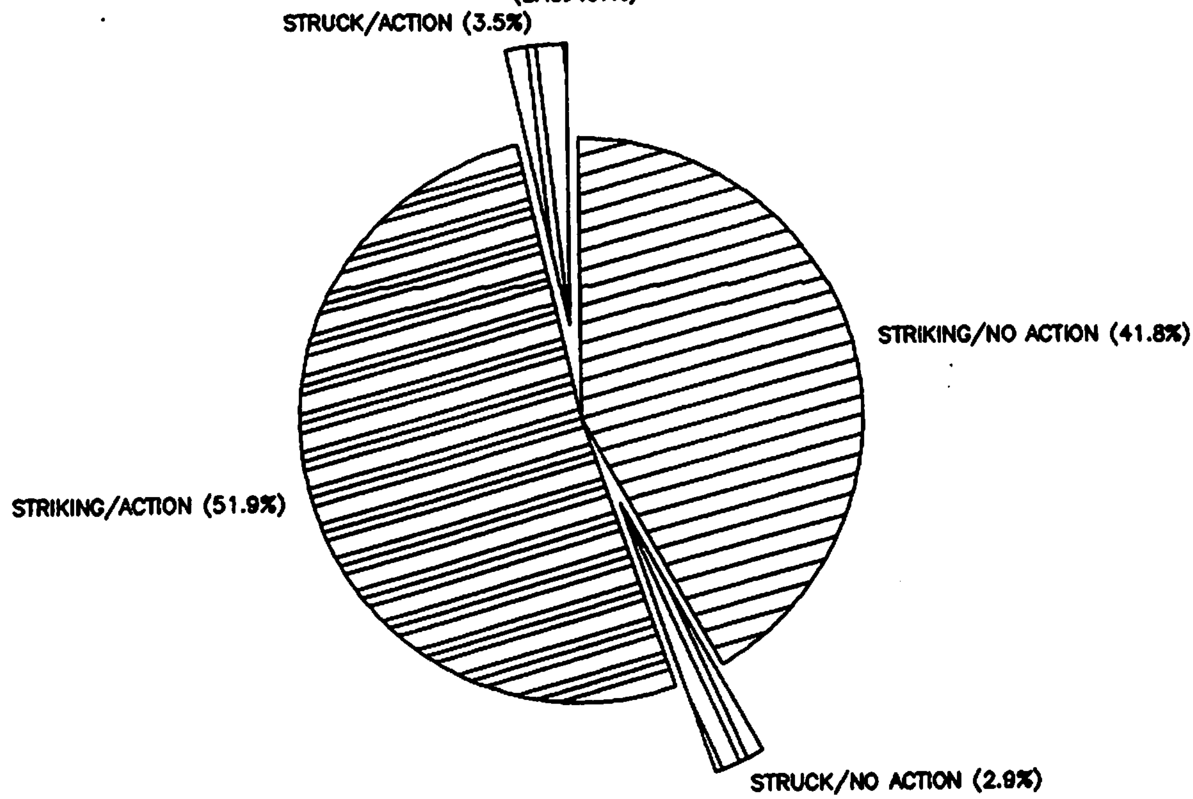


FIGURE 3

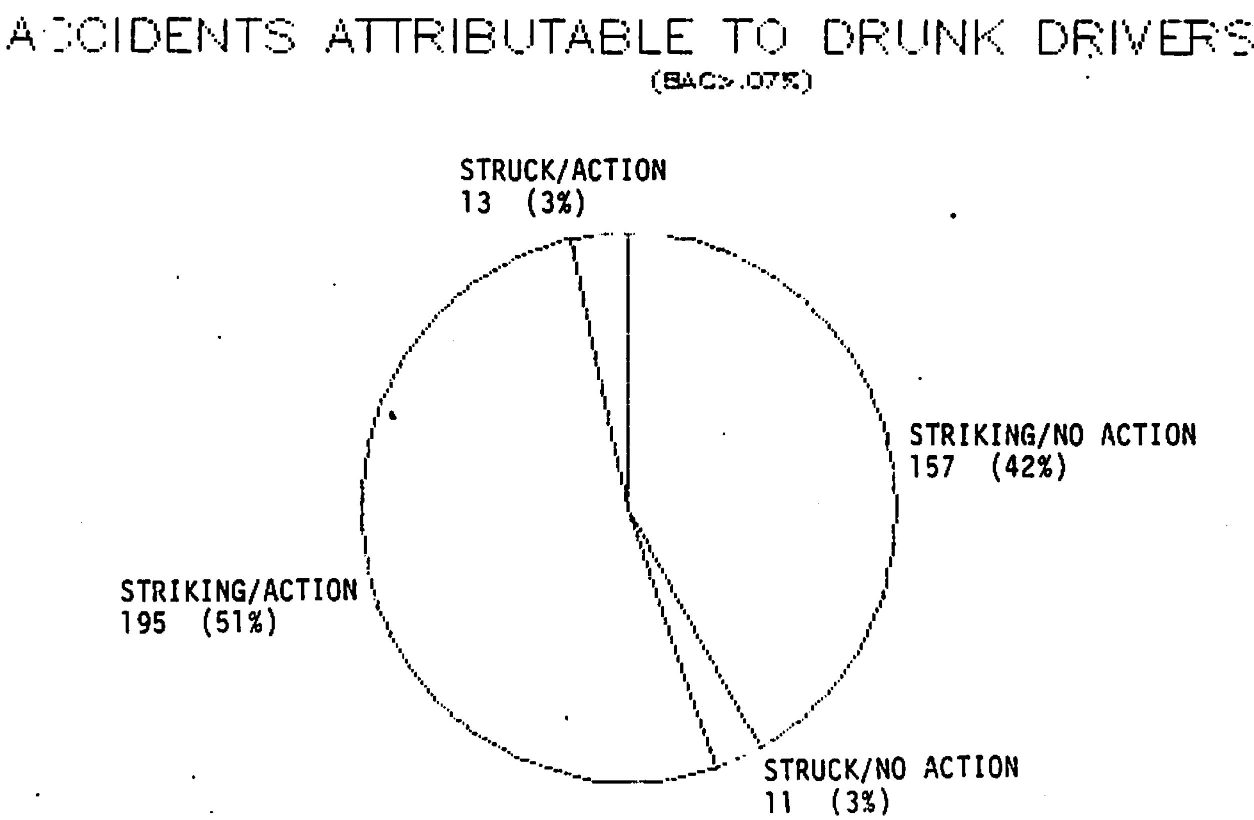
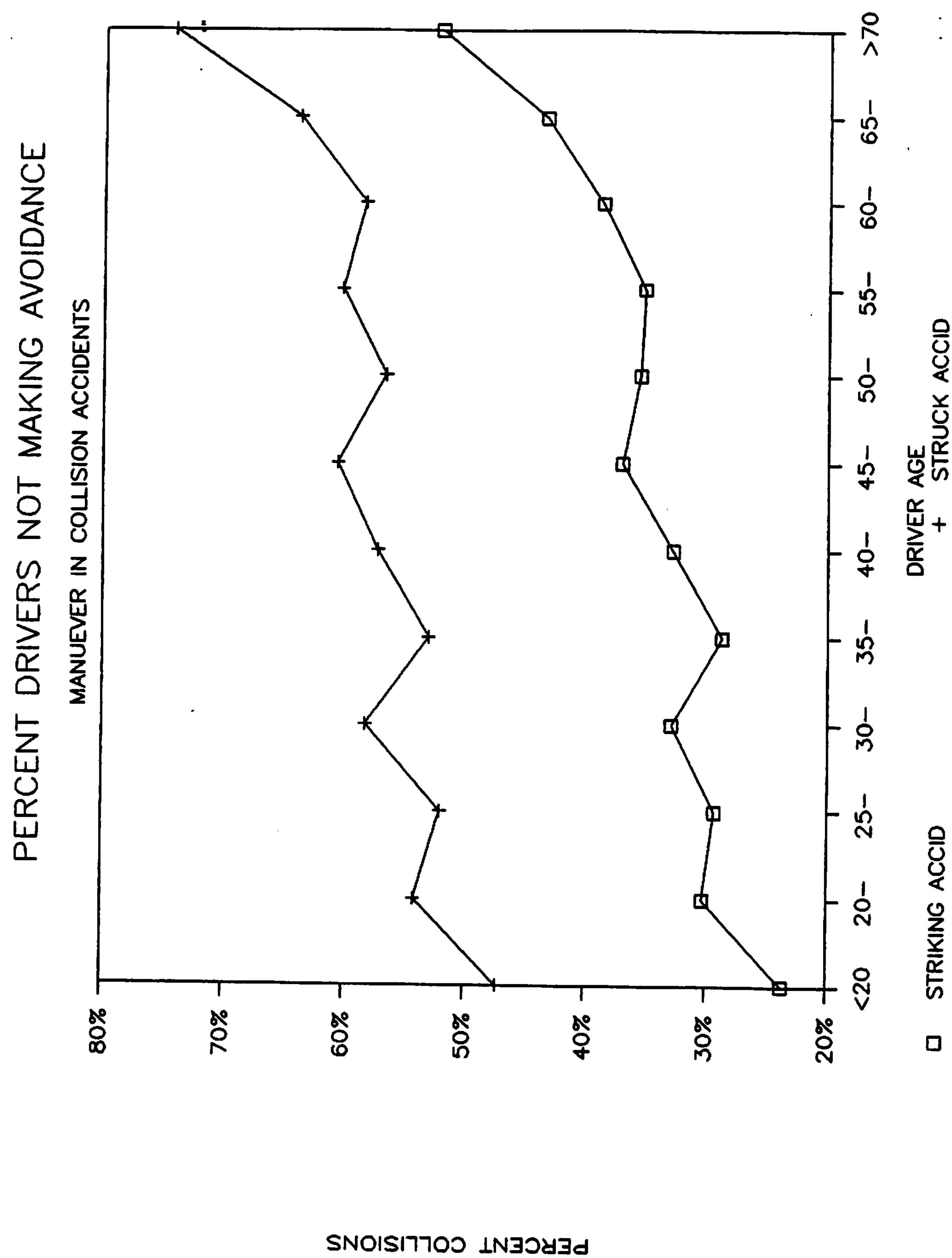

ACCIDENTS ATTRIBUTABLE TO DRUNK DRIVERS
(BAC>.07%)
STRUCK/ACTION
13 (3%)
STRIKING/NO ACTION
157 (42%)
STRIKING/ACTION
195 (51%)
STRUCK/NO ACTION
11 (3%)

TABLE 1

Percent of Drivers Making no Precollision Manuever

Driver Age	Striking	Struck
<20	24%	47%
20-	30%	54%
25-	29%	52%
30-	33%	58%
35-	29%	53%
40-	33%	57%
45-	37%	61%
50-	36%	57%
55-	35%	60%
60-	39%	58%
65-	43%	64%
>70	52%	74%

FIGURE 4


PERCENT DRIVERS NOT MAKING AVOIDANCE
MANUEVER IN COLLISION ACCIDENTS
80%
70%
60%
50%
40%
30%
20%
PERCENT COLLISIONS
<20
20-
25-
30-
35-
40-
45-
50-
55-
60-
65-
>70
DRIVER AGE
□ STRIKING ACCID
+ STRUCK ACCID

- o and 13 or 3% were "struck" vehicles whose driver took avoidance action prior to the collision.

2.2.4 MEDICATION - LEGAL AND ILLEGAL

Drivers involved in accidents meeting the above mentioned collision criteria who were found to have used legal or illegal drugs prior to collision, respectively, represent less than 0.1% of the cases meeting the collision definition.

2.2.5 DRIVER AGE

Table 1 and Figure 4 depict driver responses in accidents attributable to inattention versus driver age. The data indicate that younger drivers were more inclined to make avoidance maneuvers than older drivers. The relationship between failure to respond in a collision type accident and age appears to be linear. As would be expected, the the number of cases where the driver fails to respond is greater in accidents where the driver's vehicle is "struck" than when it is the "striking" vehicle.

2.2.6 TIME OF DAY

Table 2 distributes accidents due to inattention by time of day. Between the hours of 6:00 AM and 4:00 PM (AM Rush to Mid-Day), a higher percentage of drivers took no action to avoid an accident. After 4:00 PM, drivers were more inclined to attempt an avoidance action.

2.3 SUMMARY

Thus, in all collision accidents in which the vehicles were under way and a driver response conceivably might have avoided the collision or lessened the severity of the collision (11868 accidents), the NASS investigators found:

- o Eight percent of the cases were specifically related to the driver being inattentive;
- o One percent were related to the driver being drowsy;

TABLE 2

ACCIDENTS ATTRIBUTABLE TO INATTENTION (1982 NASS)

946 OF 11868 ACCIDENT CASES

TIME OF DAY	AVOIDANCE ACTION	%	NO AVOIDANCE ACTION	%
AM RUSH	68	13	78	21
MID-DAY	150	30	127	34
PM RUSH	91	18	59	16
EVENING	114	23	68	18
EARLY AM	81	16	40	11

- Three percent of the drivers were drunk;
- Less than 0.15% were attributable to the use of legal or illegal drugs;
- Thirty seven percent of the drivers made no precrash response of any kind; and
- The frequency of precrash response decreases as a function of driver age.

3.0 INDICATORS OF ATTENTION

Indicators of inattention have been extensively studied, including such physiological measures as EKG, EEG, pulse and heart rate, and eye blinking. Behavioral indicators would include looking patterns, driver steering wheel use, accelerator and brake applications, lane drift, and closure rate. The physiological indices reviewed are listed in Table 3 and the behavioral indices are listed in Table 4. Although a number of indicators have potential utility for use in an inattention detection system, they tend to be ambiguous and unreliable when taken singly. These indicators are reviewed in detail in the above mentioned report.

3.1 COMPLEX PERFORMANCE SIGNATURES

In response to this problem, a number of investigators have attempted to define combinations of indicators that would be more useful than single indicators alone have been. Some examples of recent efforts to develop complex performance signatures are described briefly in the following sections. For purposes of organization, they have been considered in two groups. The categories are chosen for convenience, and imply primarily a difference in perspective and assumed starting points of the investigators. The studies included in the first group are characterized by the use of multivariate statistical techniques to analyze and combine measures on selected variables. These measures are used to develop complex signatures or ad hoc models to assign a driver to a given behavioral group. The studies included in the second group, in comparison, are characterized by the assumption of some prior model of the driver. Statistical

TABLE 3
PHYSIOLOGICAL INDICATORS OF DRIVER ATTENTION

(1) Active requires and passive does not require activity on the part of the driver

(2) Obtrusive requires and remote does not require physical attachment to the driver

Indicator	Sensor	Measurement Dimension	Active(1) or Passive	Obtrusive(2) or Remote	Advantages	Disadvantages
Heart Rate & Heart Rate Variability (EKG)	Electrode or Transducer	Voltage or Pressure	P	O	Easy to monitor Could be made remote by incorporation into steering wheel Easy to interpret	May require detailed spectral analysis Individual variations are large
Brain Electrical Activity (EEG)	Electrode	Voltage Amplitude and Frequency	P	O	Established relationship to fatigue and and drowsiness	Difficult to monitor or interpret No remote sensing possible in the near-term
Skin Conductance and Electrodermal Response (EDR)	Electrode	Voltage Resistivity	P	O	Could be made remote by incorporation into steering wheel	Individual variations in galvanic skin response are large Relationship to inattention not well established
Muscle Electrical Activity	Electrode	Voltage Amplitude and Frequency	P	O	Relatively easy to monitor	Relationship to inattention weak Remote monitoring not possible in near-term
Body Activity	Observer or Switches	Number of Movements State Change Frequency	P	R		Requires observer No established correlation to inattention
Respiratory Pattern	Transducer	Frequency	P	O		Difficult to monitor Correlation with vigilance inconsistent
Critical Flicker Frequency	Self-Assessed	Null Frequency	A	R	Easy to administer Could be built into vehicle dashboard	Driver would have to stop vehicle to administer Weak correlation with fatigue
Head Nod Angle	Switch	State Change	P	O	Cheap, Commercially Available	Measures last stage of drowsiness

TABLE 4
BEHAVIORAL INDICATORS OF DRIVER ATTENTION

Indicator	Sensor	Measurement Dimension	Active(1) or Passive	Obtrusive(2) or Remote	Advantages	Disadvantages
Steering wheel reversals	Potentiometer, optical or magnetic transducer	Rate and angle	P	R	Easy to monitor Studied extensively Commercially available	Affected by vehicle/driving environment Individual variations
Accelator pedal movement	Linear potentiometer	Rate and amplitude	P	R	Easy to monitor	No established relationship to attention Individual Variations
Brake Pedal Movements	Linear potentiometer, pressure transducer	Rate and pressure	P	R	Easy to monitor	No established relationship to attention Individual variations
Vehicle position (Longitudinal, Lateral, and Heading)	Observer, sensitive guidance system, road-side edge monitor, radiation detector	Frequency, amplitude and angle, relative distance	P	R	Correlated with alcohol and drug use	Difficult to monitor Complex interactions
Looking behavior	Observer, TV monitor, oculometer	Eye position and fixation frequency, pattern and duration	P	O or R	Correlated to all dimensions of attention Can be made remote	Interpretation difficult Not useful in real time
Blink rate	As above	Rate and duration	P	O or R	Can be measured remotely	Weakly correlated with attention
Secondary tasks	Many Variations Usually Tracking		A	R	Can be a simple device	Distracts from main task

techniques may be used to determine parameter values or changes which may be used to categorize a driver.

3.2 STATISTICAL PROCESSING

A number of investigators have attempted to use multivariate statistical techniques to identify combinations of measures with greater discriminatory power than univariate indicators. In most cases, the focus of the effort has been on problems other than attentional performance; however, the approach has been fruitful, as shown in the following examples.

Lemke (1982) used factor analysis and canonical correlation to establish multivariate relationships between changes in EEG patterns and changes in driver control activity during long periods of driving in a simulator and on the road. A more popular approach, however, has been to use discriminant function analysis. Hagen (1975) derived discriminant function vectors using variables derived from four basic measures on subjects driving a point light source simulator. He found mean accelerator reversal rate, mean speed, lateral position error, and accelerator variability made the largest contributions to vectors discriminating between male and female subjects. Using this approach, he was able to develop vectors which discriminated between a number of groups including, for example, sex/violation, sex/accidents, sex/driving experience, and sex/risk taking.

Wilson et al (1983) also used multivariate discriminant analysis to develop combinations of driving performance scores of males and females during 40 to 50 minutes of on-road driving. They found that combinations of seven variables were useful for discriminating between males and females. These were: number of speed changes, number of fine (less than two degrees) and coarse (greater than 20 degrees) steering reversals, moderate (0.15g) and strong (0.3g) lateral acceleration for a period of one second or more, accelerator pedal activity, and clear road speed.

Attwood (1979) obtained five measures of driving performance during 70-mile trips driven by experienced and inexperienced drivers. He found no single variable was useful for discrimination between the groups. He derived 71 variables from the five base measures, and using multivariate discriminant analysis, he was able to develop a number of combinations which discriminated between the driver groups. For example, a driver's group could be predicted with a combination of scores on (mean lateral position) + (minimum lateral positon), or a more complex combination of scores on:

(lateral position standard deviation) + (mean lateral position)

(lateral position standard deviation) + (steering wheel reversals) + (accelerator pedal reversals)

Attwood et al (1980) used a similar approach to the development of a linear discriminant function which could be used to identify sober and intoxicated drivers. In another study, Attwood and Scott (1981) applied this approach to the problem of detection of sleepy drivers. In this latter experiment, they obtained behavioral and vehicle measures during two three-hour driving periods separated by 21 hours of maintained wakefulness. Using these scores, they developed linear discriminant functions which could be used to identify drivers in the first and second driving periods. The smallest n-variable function was based only on measures of vehicle lateral position and steering wheel activity. It was expressed as:

$$D(30) = 256\ V(1) - 159\ V(2) - 1.4\ V(3),$$

where V(1) and V(2) are the mean and maximum vehicle lane position, and V(3) is the steering wheel reversal rate in the range of 1.0 and 1.5 degrees. For longer sampling periods of 45 or 70 seconds, the best functions included lane position and accelerator pedal activity rather than steering wheel activity. The function D(30) was applied to the performance scores obtained during a second set of three-hour driving periods for one driver on one task. The power of the simple function for assigning the driver to the drowsy class, although limited, was reasonably good and demonstrated the potential utility of the approach.

3.3 FORMAL MODEL-BASED SIGNATURES

In recent years, there has been considerable interest and success in the development and application of general operator/vehicle models. Most work has used either the now classical quasi-linear describing function representation or the more recent optimal control, state space represenation. Recent and accessible reviews of these developments are presented, for example, by Allen (1982), McRuer et al (1977), Reid (1981), and Rouse and Gopher (1977). Although the optimal control, state-space approach eventually may prove to be of greatest value for describing complex, multivariate operator/system behavior, the quasi-linear describing function models are currently the most well developed.

A number of simulator and on-road studies have been conducted in recent years to evaluate model and parameter requirements, and changes for different driving situations. For example, Donges (1978) has studied straight and curved road driving, Reid et al (1982) have studied obstacle avoidance maneuvers, Allen (1982) has studied driver adaptive behavior, and Smiley et al (1980) have studied changes with driving experience.

In some recent studies, changes in the values of parameters of models have been used as indicators of changes in operator attentional state. Most of the studies have been focussed on changes associated with conditions requiring changes in the allocation of attention.

In studies of simple tracking behavior, interest has commonly been focussed on the parameters of gain, effective delay, lead-lag adjustment, and remnant. As Wickens and Gopher (1977) indicated, open-loop gain is attenuated, lead is decreased, and/or remnant is increased with diversion of the operator's attention. These authors also observed an increase in the number of holds (no tracking response) related to the addition of secondary tasks and changes in both gain and power at low and high frequencies related to changes in primary and secondary task priorities.

The results of a driving simulator study by Allen et al (1975) generally confirm the results of the tracking test studies. In this study, the effects of changed attentional state related to the imposition of a secondary visual detection task and those related to the effects of driver blood alcohol level were examined in the framework of a quasi-linear describing function model. The effects of task loading and blood alcohol level were similar in that both resulted in reduced gain, particularly at low frequencies; increased remnant; increased steering wheel activity; and increased heading and lateral position errors. There were also differences in the effects of the two types of conditions. Phase margin was not affected by driver blood alcohol level, but was increased with the addition of the secondary task. Crossover frequency, on the other hand, was not affected by the additional task loading, but decreased with increased blood alcohol level. Holds (no tracking response) on steering behavior were noted with intoxicated drivers during visual response period, but were not observed with sober drivers.

Driver/vehicle models appear to provide an excellent means for expressing complex signatures necessary as a basis for an inattention detection system. Changes in the values and relations of variables and parameters of both ad hoc and formal models have been shown to be related to changes in driver physiological and psychological states and task demands. Research such as that of Attwood and Scott suggests the possibility of developing relatively simple, useful, ad hoc models with the use of multivariate analytical techniques. This approach provides flexibility in the choice of measures to be used, but the resultant models provide little guidance for the selection of measures or derived variables to establish or improve their discriminative power. Formal models, such as those used by Allen et al, provide a fairly well known and applied conceptual framework, but may be both more restrictive and demanding with respect to the measures which may and must be used. The possible requirement for input data to establish such model parameters as crossover frequency or phase margin, for example, may limit the use of formal models to research settings. Further research is necessary, however, to establish the minimum non-performance input data for either type of model, technical means of providing this data, and the possibility of using predictive techniques to calculate probable input on the basis of driver and vehicle performance measurements.

4.0 DRIVER ALERTNESS MONITORS

The report reviewed the state-of-the-art in driver alertness monitors. Currently, there are a limited number of such devices that are commercially available. These range from the unsophisticated head-droop alarm to the microprocessor-based monitor of steering wheel driving pattern/driving time patterns that is available in Japan on Nissan's Bluebird line of vehicles. The monitors reviewed in the report are listed in Table 5.

Although not directly related to driver attention per se, the status of systems related to the vehicle and its environment were considered. These include radar warning and braking systems, navigational aids, roadside monitors, and automated highway systems. These systems could be considered as part of a multivariate approach to developing a driver alertness monitor.

The state-of-the-art in automotive electronics was briefly reviewed in the report. The practical utilization of any of the aforementioned devices depends, to a large extent, on the development of sophisticated electronics for sensing, data handling, and analysis.

5.0 CONCLUSIONS

The material reviewed in the report suggests the following:

ACCIDENT DATA

- The fact that a large portion (37 percent) of drivers involved in automobile crashes, as reported in the 1982 NASS file, took no action to avoid the collision suggests that attentional lapses are a major factor in the causation of highway accidents and that these attentional lapses probably become a more important factor as drivers age.

RESEARCH FINDINGS

- Changes in performance associated with task duration or drowsiness include: a reduction in the frequency of control responses, periodic "blockage" of all responses, an increase in the amplitude of responses, and an increase in the variability of the responses.

TABLE 5
DRIVER ALERTNESS MONITORS

Monitor System	Sensor	Measurement Dimension	Active or Passive (1)	Obtrusive or Remote (2)	Advantages	Disadvantages	Availability	Cost
Reli "Stay-A-Wake"	Optical Transducer	Steering Rate	A	R	Alerts driver when steering wheel movement rate drops below a given rate.	Standard steering movement rate must be set by driver. System effectiveness can be defeated.	Available from the manufacturer	$170
	Voltage	Vehicle Speed	A	R	Will sound an alarm when vehicle reaches or exceeds a set speed.	Speed at which alarm sounds is set by driver.		
Slarner "Driver Alert Warning Device"	Switch	State Change	A	O	Sounds an alarm when driver's head droops.	Warning does not occur until the driver is asleep.	Available from AAA	$33
Safex "Drive Alert"	Switch	State Change	A	O	Sounds an alarm when driver's head droops.	Warning does not occur until the driver is asleep.	No longer available	
Nissan "Safety Drive Advisor"	Optical/ Velocity Sensor	Rate & Frequency	P	R	Monitors and records driver's initial steering reversal rate and alerts the driver if steering reversal rate differs from this standard.	Little detail of operational principle is known to date.	Available on Nissan Bluebird models. Not imported into USA.	$85 (approx)
	Electronic Clock	Elapsed Driving Time	P	R	Alerts driver to take periodic breaks. Interval between signals is decreased by activation of headlights or windshield wipers.			
Life Technology/ Ford "Owl"	Optical Sensor	Rate	P	R	Monitors and records driver's initial steering reversal rate and alerts the driver if steering reversal rate differs from this standard.	Standard steering reversal rate can be adjusted by driver. System effectiveness can be can be defeated.	No longer available	

(1) Active requires and passive does not require activity on the part of the driver.

(2) Obtrusive requires and remote does not require physical attachment to the driver.

- In controlled experiments, averaging across subjects who are exposed to the same conditions, there are reliable changes in performance which are monotonically related to attentional state.

- Examination of the performance of the individuals in these studies indicates that while performance of selected tasks decreases with degraded attention, the relationship between the changes in performance and the attentional state varies significantly between the subjects.

- The use of multiple performance indices will enhance the discriminative power of the attentional discrimination system.

- Although performance changes can reliably reflect modifications in attentional state, the most difficult problem in detecting degraded alertness will be to discriminate the effects of these changes from those imposed by the driving environment.

DRIVER ALERTNESS SYSTEMS

- Proprietary alertness indicators fall into two functional classes: those which evaluate performance and those which evaluate the physical or physiological state of the subject.

- Indicators that are based on physiological or physical concomitants of attention are likely to be too cumbersome to achieve widespread use by private vehicle operators.

- Indicators that are based on the performance of an artificially constructed secondary task are likely to be distracting to the driver and, therefore, potentially hazardous. However, it may be possible to use performance measurements on noncritical tasks which are normally required, such as instrument scanning, as an index of alertness.

- A driver attention indicator, regardless of what its behavior, must be able to "learn" the shape of the normal performance curves particular to the individual driver. Then it must be able to sense deviations from this "normal" that are not the result of changes in the environment and provide warning of changes in alertness.

- Of the proprietary devices reviewed, only one system is currently installed on production passenger vehicles in Japan. This sytem is based on a multivariate analysis approach and learns the patterns of driving performance of the individual driver, and represents a potentially promising approach.

- The existing electronic systems and the near-term projected advancements lead us to conclude that the electronics soon will be available to reliably track and analyze any practical driver alertness monitoring system.

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