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# Potential for Driver Attention Monitoring System Development

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16. Abstract

The objective of this effort was to determine the potential of developing techniques and methods for reducing the occurrence of highway accidents attributable to degraded driver alertness.

Lapses in driver alertness are thought to be a major factor in the causation of serious motor vehicle accidents. The most recent NASS data was analyzed to determine the extent of this problem.

Potential methods and techniques for reducing driver alertness-related problems include the development and use of:

- Vehicle subsystems which automatically detect reduced driver alertness through erratic driving and make the driver aware of the problem and/or slow or stop the vehicle (e.g., eyelid-droop meters);
- Vehicle subsystems which amplify sub-threshold signals and make them more apparent to the driver (e.g., radar-based obstacle detection and warning systems); and
- Vehicle subsystems which automatically detect unsafe conditions and slow or stop the vehicle (e.g., radar-based braking systems).

This study focused on the potential of devices to detect driver alertness problems and concluded with recommendations for the development and performance of a demonstration program to further evaluate these techniques and methods.

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# PREFACE

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 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.

The authors gratefully acknowledge the assistance of those who made this report possible. First, we thank Robert Nicholson; Chief, Crash Avoidance Division, and Michael Perel, Research Automotive Engineer, of NHTSA's Office of Vehicle Research for their support and guidance.

We would like to thank the private corporations who provided information on the operation of their inattention monitors and the development history of their products.

We appreciate the assistance of Mr. Jack Yamaguchi and of Messrs. Maeda and Iizuka of Nissan Motor Co., Ltd. for their insights on research overseas in the area of driver alertness.

The authors would also like to thank Dr. J. K. Hedrick and Farid Kaymaram of the Massachusetts Institute of Technology's Department of Mechanical Engineering for their review of the methodologies required for a model based approach to driver inattention detection.

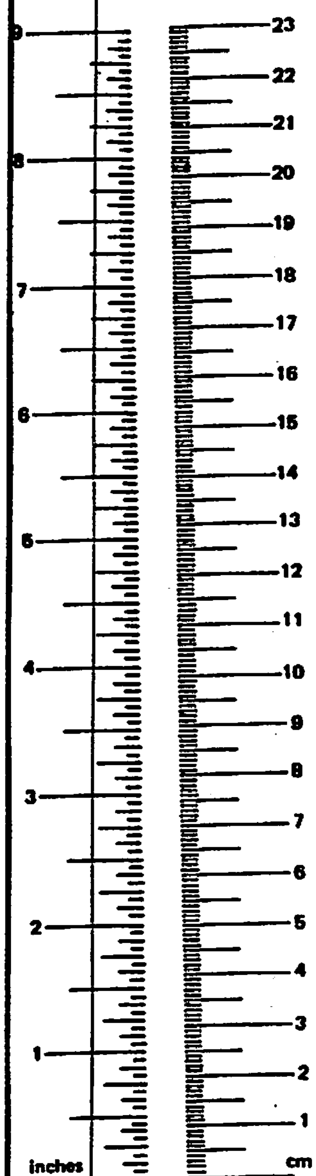
The authors would also like to thank Ms. Robin Barnes and Ms. Melodie Esterberg for their support in the preparation of this document.

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

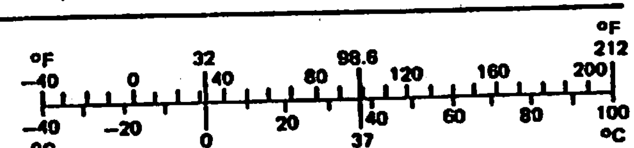
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286, Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## Executive Summary


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 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 previous studies, as well as reiterating the complexity of driver attentional processes. It was apparent from reviewing the available data that combinations of indicators of attentional state and indicators of the driving environment could significantly improve the accuracy of driver attention monitoring.

The 1982 NASS data was analyzed to develop hypotheses on the influence of driver inattention on traffic accidents. The 1982 data was selected as it is the first file that records detailed information on the driver's role in accidents. The data showed that a large portion (38 percent) of the drivers involved in automobile accidents took no action to avoid the collision, which suggests that attentional lapses are a major factor in the causation of highway accidents.

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 limited number of these devices are commercially available at present. These devices range from a simple head-droop alarm to a microprocessor-based system of steering wheel motion pattern/driving time monitor developed in Japan by Nissan. Both physiological and behavioral indicators of inattention were investigated with respect to the technology of sensing the indicator and relative advantages/disadvantages of each as a practical monitor of inattention.

In conjunction with investigating available sensing devices, a review of the state-ot-the-art in automotive electronics was conducted to determine the practicality of incorporating existing or potential alertness monitoring systems into automobiles.

Overall, the results of this research effort indicated that attentional lapses are a major factor in the causation of highway accidents. It was concluded that a research effort to experimentally investigate multivariate techniques for monitoring driver attention would have a high probability of identifying useful methods.

## 1.0 INTRODUCTION

The following document provides an overview of the potential value of research into driver attentional processes. Section 1 outlines the status of this research into driver attentional processes and provides capsule descriptions of the physical and psychological states which are related to reduced driver alertness. Section 2 outlines the statistical evidence from the 1982 National Accident Sampling System (NASS) data of the relationships between driver attention and traffic accident data. Section 3 details the prior research in the area. Section 4 describes the technology currently available for sensing degraded alertness in drivers. Section 5 provides preliminary conclusions with regard to research directions in the area. The appendices provide reproductions of the material describing proprietary alertness devices and the NASS (National Accident Sampling System).

## 1.1 BACKGROUND

To a large extent, the safe operation of any system requiring direct human control is dependent 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, or does not select the appropriate stimuli, or does not respond in a timely manner, safety will be degraded.

### 1.1.1 COUNTERMEASURES

Available driver inattention countermeasures include work-rest scheduling, educational campaigns, use of chemical stimulants and the detection of degraded alertness through sensor systems. In industrial and military settings, the alleviation of alertness-related safety problems are generally handled through the establishment and enforcement of duty schedules. The establishment of, 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 self-owned truck operators. Educational and public information campaigns range from "defensive driving" courses through public service announcements prior to national holidays. Perhaps the most popular countermeasure is the use of legal and illegal chemical stimulants (particularly caffeine) to improve alertness.

This paper deals with the potential for the identification, evaluation, and refinement of techniques for detecting, in "realtime," reduced driver alertness in the vehicle. A variety of devices have been developed and marketed as "alertness detectors." These devices have been widely adopted by the railroad industry and have found limited use in the trucking industry as well. A number of aftermarket devices are currently available to the private driver and at least one major manufacturer, Nissan Motors Ltd., has installed such a device in a production vehicle. The primary goal of these devices is to provide a signal to the driver that he or she is not adequately attentive--a common secondary goal is to arouse the driver.

### 1.1.2 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 the definitions given to attention-related problems.

Shinar et al. (1978) provided a list of dictionary definitions of attention, which also defined inattention as "a failure to pay attention." Shinar summarizes the dictionary definitions as either an activity, a state, or a process of the internal condition of the organism. Section 3.1 of this report discusses Shinar's concepts in more detail. 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 describe their impact on driving performance:

- Drowsiness: 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 in human and infrahuman organisms. These relate to the diurnal hormonally-regulated rhythms which cause the periodicity 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 and/or exposure to environmental stressors such as temperature and humidity extremes, excessive acoustic noise levels, and/or 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 a decrease in response accuracy by the driver, which can result in the requirement for a greater number of responses 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 and/or too many responses to make per unit 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 outputs. 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 affect 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 behavioral changes caused by alcohol ingestion that result in dangerous driving practices.

- Simple Inattention: Here the driver is either not attending to any stimuli or not attending the proper external stimuli. This behavior can be described as "daydreaming" or "wool gathering" 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.

## 1.2 GOAL

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 or 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 is readily measured. The challenge is to discriminate reliably and accurately between changes in reponses due to driver alertness and those changes imposed by driving conditions in the real world. The goal of this report is to assess the near-term feasibility of driver alertness measurement.

## 2.0 ACCIDENT STATISTICS

### 2.1 ACCIDENT DESCRIPTIONS

In order to develop hypotheses with regard 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 as it is the first file to provide detailed information on the driver's role in traffic accidents. The following factors were used in analyzing the file:

#### 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 is clearly more important with regard to the role of the driver in the striking vehicle. However, in many cases, if the driver of the struck vehicle properly responds in a pre-accident situation, the accident can be avoided or its severity reduced. In order 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.

### 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 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 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%.
- Age of Driver: Drivers were grouped by age: less than 25, 25 to 55, and more than 55 years old.

### 2.1.3 ACCIDENT FACTORS

- Land Use: The accidents are grouped in terms of urban or rural site.
- Time Period: The day was divided into five time periods: Early AM, which represents accidents that occurred between the hours of midnight to 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, which is from 7:00 PM to Midnight.

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

- o Number of Occupants: The data was examined to determine the influence of the presence of passengers in a vehicle (greater than 1) on the accident. Vehicles having the driver as the only occupant are designated as occupant equal to one.

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

## 2.2 NASS DATA

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.

### 2.2.1 ALL COLLISIONS

A broad operational definition of driver inattention is **the attentional state where the driver fails to respond to a critical situation.** Table 1* represents breakdowns of 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:

- o 2,665 or 22% were "striking" vehicles whose driver took no avoidance action prior to the collision;
- o 1,838 or 15% were "struck" vehicles whose driver took no avoidance action prior to the collision;

*All tables found in Appendix A.

- 5,916 or 50% were "striking" vehicles whose driver took avoidance action prior to the collision; and
- 1449 or 12% were struck vehicles whose drivers took avoidance action prior to the collision.

In short, in all collision accidents in which the vehicles were under way and a driver response might have conceivably avoided the collision or lessened the severity of the collision , 38% of the drivers involved took no avoidance action. These relationships are depicted in Figure 1.

Examination of the other factors in Table 1 (Appendix A) suggests that the drivers' age may be related to the probability of an avoidance response in the pre-collision situation. Figures 2 and 3 depict the differences in age distributions of drivers making avoidance responses and those not making such responses. Drivers over 55 years of age represent 18% of those making responses and only 11% of those not making avoidance responses (differences of more than 2% are statistically significant).

As was noted in Section 2.1.1, single vehicle accidents are, by definition, included in the striking and struck categories. The percentage of single vehicle accidents in the 1982 NASS data is presented in Table 2 in Appendix A.

### 2.2.2 INATTENTIVE

Table 3 represents breakdowns of the frequency of all "collision" accidents where the driver was judged to be "inattentive," 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, 946 or 8% of all collisions involved vehicles in accidents that met these criteria. In these accidents:

- 293 or 31% were "striking" vehicles whose drivers took no avoidance action prior to the collision;

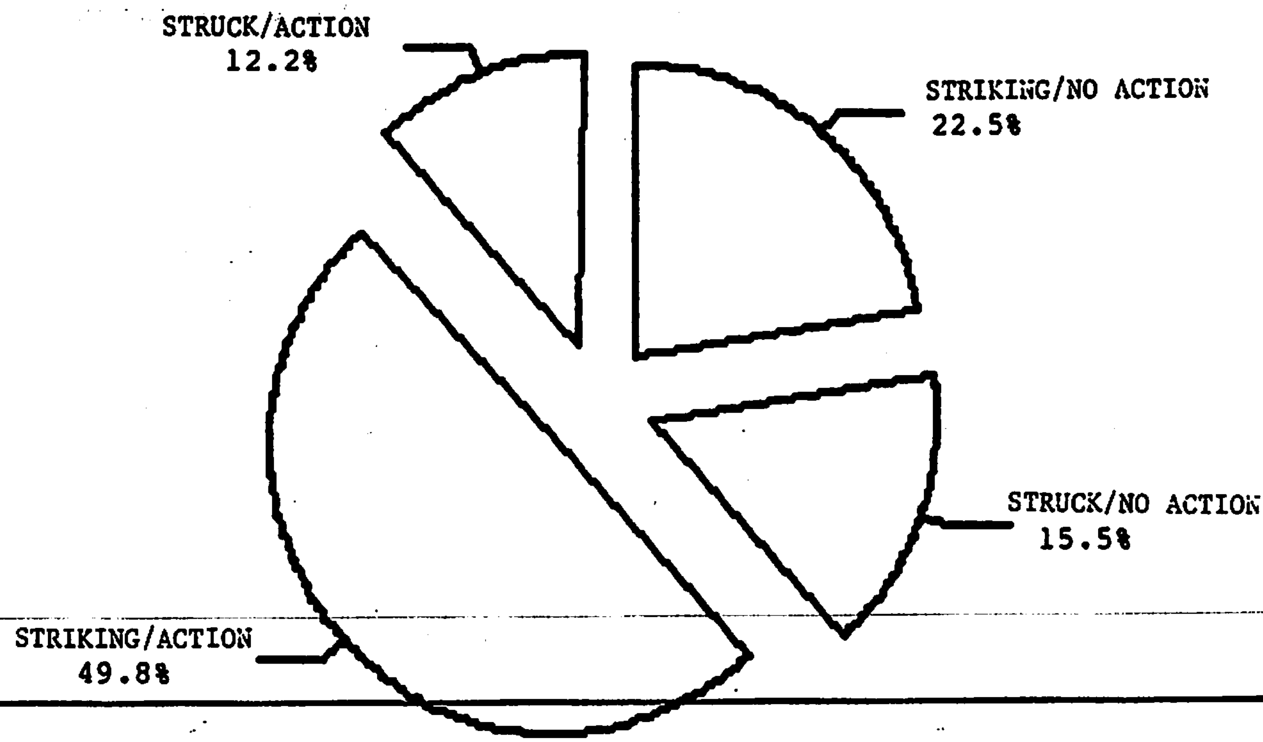



FIGURE 1. DRIVER RESPONSES IN ALL COLLISION ACCIDENTS

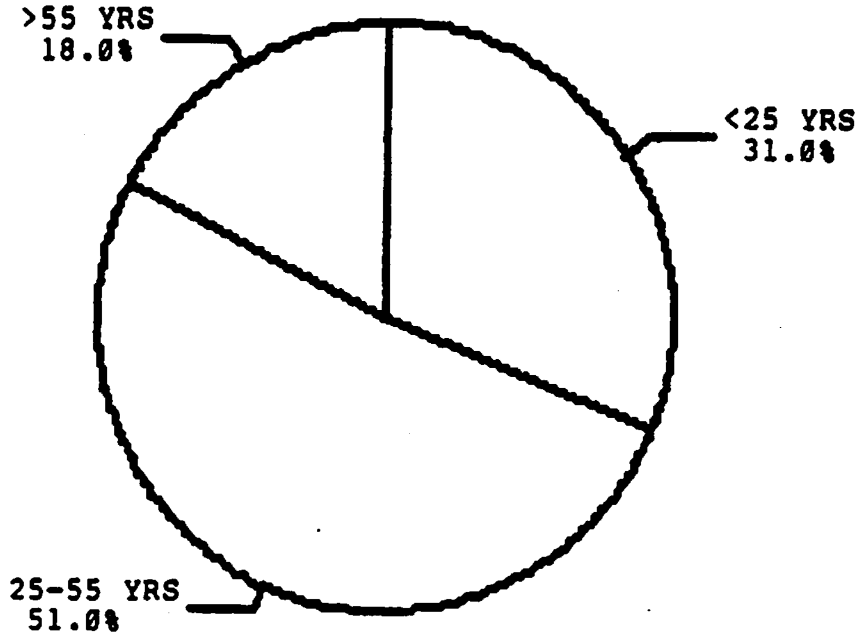



**FIGURE 2. DRIVER RESPONSES IN ALL COLLISION ACCIDENTS - NO ACTION**

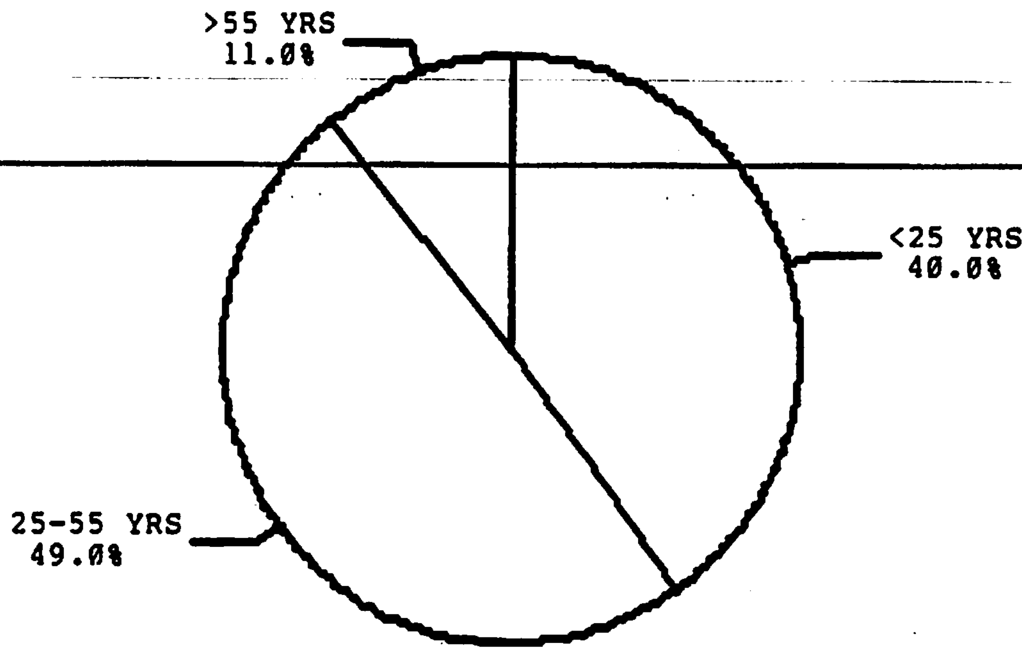



**FIGURE 3. DRIVER RESPONSES IN ALL COLLISION ACCIDENTS - ACTION**

- 80 or 8% were "struck" vehicles whose drivers took no avoidance action prior to the collision;
- 509 or 53% were "striking" vehicles whose drivers took avoidance action prior to the collision; and
- 64 or 7% were "struck" vehicles whose drivers took avoidance action prior to the collision.

### 2.2.3 DROWSY

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

### 2.2.4 DRUNK

Table 5 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:

- 157 or 42% were "striking" vehicles whose drivers took no avoidance action prior to the collision;
- 11 or 3% were "struck" vehicles whose drivers took no avoidance action prior to the collision;
- 195 or 51% were "striking" vehicles whose drivers took avoidance action prior to the collision;
- and 13 or 3% were "struck" vehicles whose drivers took avoidance action prior to the collision.

### 2.2.5 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.

## 2.3 ADDITIONAL NASS DATA

Several additional tables have been extracted from the 1982 NASS data to depict statistically significant findings (differences in the data of more than 2%). These tables can also be found in Appendix A.

Table 6 depicts driver responses in accidents attributable to inattention versus driver age. Drivers under 55 years of age were more inclined to make avoidance maneuvers than drivers over 55. Table 7 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.

In Table 8, accidents attributable to drowsiness are also broken down by time of day. Early AM (midnight to 6:00 AM) and AM Rush (6:00 AM to 10:00 AM) periods show a higher percentage of drivers taking no action to avoid accidents. In accidents occuring between 10:00 AM and midnight, the drivers were more likely to make an avoidance maneuver. In Table 9, accidents attributable to drowsiness are divided into groups by the number of occupants. In vehicles with more than one occupant, the driver was more inclined to make an avoidance maneuver than in vehicles where the driver was alone.

## 3.0 DRIVER/VEHICLE MONITORING

A summary of our current state of knowledge of indicators of driver inattention is presented in this section. Zaidel et al. (1978) documented a comprehensive review of related studies of the concept of attention as well as studies related to the problem of attentional performance. Additional studies of operator performance, conducted since 1978, were reviewed during this effort to update the Zaidel et al. study. The results presented in these more recent studies confirm both the general conclusions drawn in previous studies and the complexity of the problem of driver inattention.

The following sub-sections begin with a few definitions of terms, followed by a brief overview of indicators of driver inattention. The definitions are given to establish a point of reference. The discussion of indicators is included primarily to highlight the problem of developing useful measures of attention for practical application in inattention detector systems.

### 3.1 DEFINITIONS

Many investigators have noted the ambiguous use of the terms "arousal," "alertness," and "attention." Although each of these concepts is unique, there is some overlap of connotation in the context of driver attention. In their discussion of these concepts, Zaidel et al. (1978), for example, note the use of the terms to connote a level of specificity of stimuli a driver is prepared to receive. The term "arousal" is used to connote a general receptivity to environmental stimuli; "alertness," a more specific preparation to receive and respond to a broad class of stimuli; and "attention," to connote an even more specific preparation to receive and respond to task-relevant information. They also discuss the uniqueness of the concepts; and for the purpose of understanding and developing countermeasures for inadequate attentional performance by the driver, it is important to stress these differences and attempt to refine the use of the terms.

A discussion of the concepts and possible definitions is beyond the scope of the present review. Therefore, to provide continuity with their report, the brief definitions given here generally follow those given by Zaidel and his co-authors in their review. Attention will refer to an internal action or process of focusing perceptual and information processing capacities and activities on job-relevant information. Attentional performance may be described in terms of four continuous dimensions or attributes. In short, these are:

- Intensity - the level of total effort;
- Distribution - the division or relative allocation of effort to different sources of information;
- Regularity - the maintenance of level and continuity of effort over time; and
- Mode of control - the level of active driver control and direction of attention.

These dimensions or attributes are quite useful, although it is apparent that they are not independent and further research is necessary to delineate them and to understand their interrelationships.

At a given moment, a driver's attentional performance may be characterized with values on a continuum for each of the attributes, and the values may change over time as a result of changes in task demand or other factors. To emphasize the multidimensional character of attentional performance, a concept of attentional state will be used, with the state defined as a function of the combination of values on each of the dimensions or attributes. Inattention, then, may be defined as an attentional state that is not appropriate to the attentional requirements of the driving situation.

In the present context, the terms arousal and alertness will be used to refer to internal states of a driver. The general concept of arousal is quite complex, but it is useful to consider it in even a simple form with reference to a continuum of levels of arousal ranging from the level in deep sleep, through somnolence and alert wakefulness, to excitement and panic. The levels of arousal and associated variation of behavior are assumed to reflect and to be described in terms of changes of a constellation of neurological, physiological, and emotional states

(Malmo, 1959; Duffy, 1962; Stroh, 1971; Schmolling and Lapidus, 1972, 1972; Kahneman, 1973; Lacey and Lacey, 1974). Alertness, a psychological state of readiness to receive and respond to stimuli, also, may be described in terms of a continuum of levels.

Measures of driver arousal, alertness, and attentional performance are correlated, but the interrelationships are not simple. For example, minimal levels of arousal and alertness are necessary for a given level of attentional performance. However, adequate levels of arousal and alertness do not necessarily imply adequate attentional performance. An aroused, alert driver may not be appropriately attentive to the driving task. In this context it may also be noted that the form of the relationship of performance efficiency to alertness generally can be considered to be a continuously increasing function of alertness levels. In contrast, the relationship to arousal level is usually considered to take the form of an inverted U, with poor performance exhibited with extremes of arousal and best performance occurring at intermediate levels. Inattention, then, may be related to a very low state of arousal of a drowsy driver or to a high level of arousal of a panic stricken driver facing an imminent crash.

## 3.2 INATTENTION INDICATORS

Generally speaking, an inattention detector may be considered to be a system for measuring and evaluating attentional performance, and for providing a response based on the evaluation. Since attention is defined as an internal activity, and attentional performance is multidimensional, a detector must be based on measurement of an event, state, or activity or the driver or vehicle, which is an external indicator of the level of performance on one or more dimensions of attentional performance. In addition, since inattention is defined relative to task requirements, an indicator of attentional demand is required to evaluate the measure and establish the adequacy of performance.

Investigators have used a variety of measures on the driver and vehicle as indicators and these may be classified in a number of ways. Zaidel and his co-workers, for example, organized their discussion of indicators on the basis of two classes of measures: measures of driver/vehicle performance and physiological measures. To provide continuity with their report, the same approach has been taken here; although, in addition, the indicators are conceptualized as primary or secondary indicators. Measurements of events more or less directly related to attention, such as failure to detect critical signals, are considered primary indicators. Measurements of events more directly related to driver states other than the attentional state, although they may be used, are considered to be secondary indicators. For example, measurements of EEG Beta power are more direct indicators of arousal state than of attentional performance. Such measures indicate only a state that may be considered to be consistent or inconsistent with some range of attentional performance.

### 3.2.1 PHYSIOLOGICAL INDICATORS

A number of different measures of physiological state or activity have been used in studies of attentional performance. Among these, measures of brain and heart electrical activity have received the most attention. These measures are, at best, secondary indicators of attentional performance and are more directly related to arousal state than to attentional state. Most of the measures are quite ambiguous and useful only to indicate a state consistent with low levels of intenstity of attentional effort. Otherwise, they tell us little about a driver's attentional state.

#### 3.2.1.1 BRAIN ELECTRICAL ACTIVITY

In laboratory studies, certain component frequencies of the electroencephalogram (EEG) have been found to be useful markers of a subject's transition from an alert to a sleeping stage. Typically, increased appearance of Alpha frequencies (8-13 Hz) is considered to be a signal of relaxation and transition to a drowsy state. Theta (5-7 Hz) and Delta (0.5-4 Hz) activity replace Alpha activity as the subject continues to relax and fall asleep. The results of relevant past research have commonly shown increased appearance of

EEG components indicative of reduced arousal and correlated changes in subject performance after prolonged periods in a low demand task. Alpha activity has been observed often in the records obtained during periods of extended driving, and rarely, Delta activity has been observed. In one study, arousal levels were apparently extremely low and Delta activity, correlated with lane drift, was observed in the records obtained during on-road tests.

More recently, Lemke (1982) found similar changes in EEG indicative of reduced arousal and correlated changes in the coarseness of driver control performance during long periods of driving in a simulator. These changes were not clearly confirmed in on-road tests, however. Good EEG records are difficult to obtain during on-road tests; and in an effort to overcome this problem, Kazuyoshi (1976) used the ratio of Alpha and Beta (15-25 Hz) activity as an indicator of driver fatigue. During driving periods of seven to ten hours, the level of Beta activity, usually associated with alertness, generally decreased and the appearance of Alpha activty increased.

In recent years, investigators have shown some interest in cortical evoked response potentials (ECP), particularly the P-300 attribute, as a measure of mental workload and attention. In his review of physiological measures of mental workload, Wierwille (1979) recalls that ECPs tend to change as attention is directed to a stimulus source. He also notes that they change with operator attitude and understanding of instructions. In addition, as Isreal et al. (1980) point out, the magnitude and latencies of the components of the ECP vary with the physical and informational properties of the stimulus event as well as the subject's expectancy and cognitive response to the stimulus. The research of Wickens (1977) and Wickens et al. (1980), as well as that of Isreal et al. (1980) and others, suggest that ECP is definitely, but complexly, related to the attentional state of an operator. However, considerable research will be required to clarify the relationships of ECP components to attentional and cognitive processes and to show their utility as a basis for a detector of inattention.

Some measures of brain electrical activity obtained through EEG analysis appear to be good indicators of inattention when they are present. The appearance of

Theta and Delta activity, for example, is usually taken as a sign of a transition to, or actual sleep, and indicates a driver state incompatible with adequate attentional performance. Thus, these measures have been found to be correlated with such behavioral indicators as missed signals and coarseness of vehicle control. They are secondary indicators, however, and no inference can be drawn from the absence of the indicator. The driver may or may not be attentive. Also EEG components, which appear to be good indicators when present, appear late in the subject's period of transition to an inattentive state and a significant period of inattention probably precedes the appearance of the indicator. ECP changes may eventually be found to be good indicators, but our understanding of the source of significance of these changes is meager, and their utility as indicators is yet to be established. The primary use of measures of brain electrical activity appears to be as a research and development tool. Clean records are difficult to obtain, however, and averaging and processing of several time samples of activity is usually required to extract useful information.

#### 3.2.1.2 HEART RATE AND HEART RATE VARIABILITY

Operator heart rate has been found typically to decrease, and heart rate variability to increase, during extended periods of low workload under uneventful conditions. In a study not cited by Shinar, Laurel and Lisper (1976) found that driver heart rate decreased during two-hour highway driving periods on each of three days. The change was greatest during the first, and least during the third period of driving. Watanabe et al. (1982) also observed decreased heart rate levels in drivers of high speed electric trains during the second and later hours of a 260-minute high speed, monotonous driving period. Kazuyoshi et al. (1976), however, found no changes in driver heart rate during seven to ten hours of on-road driving. In a recent study using a driving simulator study, Wierwille and Muto (1981) observed increased driver heart rate variability with driver time up to 150 minutes. Conversely, Sekigvchi et al. (1979) have observed that heart rate variability tends to decrease with increased workload and presumably with increased attention.

Investigators have used many different measures of heart activity and the conclusions drawn from a study may depend on the measures used. This problem was illustrated recently by Egelund (1982), who re-analyzed data obtained by Nygaard and Schiotz. They had obtained heart activity measures on eight relatively inexperienced drivers during four-hour, 350 kilometer trips. All subjects reported high levels of fatigue, although none accepted rest stops from fear of appearing weak. No significant changes in heart rate or standard deviation of heart rate were observed, however. Egelund performed a detailed spectral analysis of their heart activity data and found a small, but statistically significant change in the 0.1 Hz component of the heart rate variability. In general, it was low at the beginning of the trip, increased during the trip, and then decreased toward the last part of the drive.

Heart rate and heart rate variability are often, although not consistently, observed to be correlated with time task. In part, inconsistencies in the results of different studies reflect the complexity of the factors affecting heart activity. Opmeer (1973) and Erikson (1975) have noted the large number of measures of variability and the lack of high correlation between them. Recent investigators have focussed their attention mostly on heart rate variability and the attempt to find a reliable measure. As Hyndman and Gregory (1975) observe, the 0.1 Hz activity has been found to have the highest correlation with measures of workload, and light physical activity, per se, does not affect it. Considering this finding and the results of the analysis by Egelund mentioned above, it is possible that this measure may have some potential as a secondary indicator of inattention.

### 3.2.1.3 OTHER PHYSIOLOGICAL INDICATORS

Several other measures of physiological activity have been used by investigators of fatigue, inattention, or increased attentional demand. These measures include, for example, muscle and skin electrical activity, respiratory patterns, critical flicker frequency, pupil size, eyeblinks, and gross body movement. In the past, investigators have found these measures to be inconsistently correlated with fatigue or length of time of driving.

In a recent study of locomotive engineers, Kazuyoski (1976) found that during trips of seven to ten hours, driver critical flicker frequency, number of galvanic skin responses, and inspiratory number and volume decreased with time into task. Watanabe (1982), also observing locomotive engineers, noted that critical flicker frequency was depressed and gross bodily movement increased after 200 minutes of driving. Wierwille and Muto (1981) also reported increased gross bodily movement of subjects after extended periods of driving a simulator.

Electrodermal response and skin resistance have been found to be quite ambiguous as indicators of attentional state. Erwin et al. (1973), in a study of the electrophysiological correlates of drowsiness, found that skin resistance decreased and skin potential became less negative with time into task. Skin potential changes were not consistently correlated with changes in EEG components, however. Helander (1979) has suggested that increased electrodermal voltage is a relatively slow response to changes in mental demands in a driving situation. His data suggest the possiblity of the use of changes as an indicator of changes in attentional demand, but not as an indicator of inattention.

Recent research that has included studies of changes in subjects' pupil size has been mostly focussed on the problem of measuring relative workload. Wierwille (1979) reviewed a number of studies that confirm a general conclusion that subjects' pupils dilate with increases in mental workload and tend to constrict under conditions of overload. Pupil constriction, thus, may indicate inattention related to excessive attention demand.

In past research, blink rate has been typically found to increase with increased driver fatigue. Recently, Watanabe (1982) reported that blink rates of train drivers increased during long-duration, monotonous trips. Wierwille (1979) noted that blink rate tends to decrease with increased mental workload, and Rockwell et al. (1973) have reported differences in blink rate related to driving task. Rockwell found, for example, that the blink rate for drivers on a freeway approach ramp was somewhat higher than that for drivers on the freeway approaching the ramp.

These indicators of operator physiological state have not been found consistently correlated with subjective fatigue, length of time of activity, or other indicators of attentional state. They are strongly affected by many personal and situational variables, and evidence for correlation with driver attention is so weak that they appear to have little potential for use as detectors of inattention.

### 3.2.2 OPERATOR BEHAVIOR

#### 3.2.2.1 LOOKING BEHAVIOR

Looking behavior is possibly one of the most direct indicators of attentional performance, although fixation does not necessarily indicate attention. Conversely, the lack of fixation does not necessarily indicate lack of attention. Mourant and Rockwell (1971), for example, have emphasized drivers' use of peripheral vision to obtain guidance information.

In past investigations, it has been found that eye movements become sluggish under conditions resulting in reduced driver arousal, as with the development of driver fatigue due to sleep debt, demanding visual performance, as in driving for long periods, and with alcohol intoxication. With fatigue, the number of pursuit movements has been found to increase, but the lateral velocity of eye movements decreased. Fatigue has also been found to result in a narrowing and change of the field of visual research. Similar changes in the field of search have been found with alcohol-intoxicated drivers, who also showed a tendancy to fixate on passing cars less frequently than sober drivers.

Recent research, also, has shown changes in the focus of driver attention and apparent selective narrowing of the attentional field as the result of task demands as well as alcohol intoxication. As noted in the review by Shinar et al., Mourant and Rockwell found that in straight-ahead driving, drivers tend to concentrate their fixations near the focus of expansion. In comparison, Shinar et al. (1977) found that drivers negotiating curves concentrated their fixations intermittently on the position of the road ahead and on the road edge or lane markers. Curve scanning was begun two to three seconds prior to entering the curve. Fixation durations were similar during approach and curve negotiation, but durations tended to be longer for dangerous curves. Williams (1982) found that reaction time to peripherally presented stimuli increased when the cognitive difficulty of a foveally presented visual task was increased. Moskowitz et al. (1976) also found that alcohol intoxication resulted in increased driver reaction time to visual stimuli requiring decisions.

Ziedman et al. (1980) noted a shift in attention from roadway position control to speed control, and both Ziedman and Moskowitz (1976) indicated that the horizontal distribution of dwells did not change with increased driver BAC and also reported that marijuana had no effect on any measure of looking behavior. In his discussion, Moskowitz noted that data obtained in previous on-road studies were inconsistent. Shinar reviews Belt's (1969) work, which found drivers' horizontal fields to be constricted with increased driver BAC. In contrast, Mortimer and Jorgeson (1972) did not. Both Belt and Mortimer reported that fixation duration increased with BAC, although Belt found this to occur only in open-road driving and not in car-following situations.

A similar restructuring of the attentional field was shown in a study of pilot workload by Tole et al. (1982). Both experienced and inexperienced pilots decreased the number of looks at secondary instruments and increased dwell times on primary instruments as mental workload was increased. The shift in the pattern of looking was most pronounced for inexperienced pilots. Wierwille (1978) also noted that large eye movements decreased as pilot workload increased.

Ziedman et al. (1980) and Moskowitz et al. (1976) also analyzed in detail the eye movement patterns of drivers under the influence of alcohol or marijuana while driving a simulator. They found that with increased driver BAC, mean dwell time and variability increased, dwell frequency decreased, and pursuit frequency increased. Pursuit dwell time was variable and saccade durations increased. These results are consistent with those obtained under conditions designed to induce driver fatigue. Considering the several studies together, it is apparent that the general pattern of sluggish eye movements is always found with drivers influenced by conditions designed to result in low arousal, but some differences in details may reflect an interaction of subject and specific situational factors.

The strong interaction of attentional effort and eye movements is seen in the results obtained by Gopher (1973) in a laboratory experiment. In this study, subjects listening to an auditory message showed reduced spontaneous eye movements, and selective monitoring of messages in one ear resulted in a pattern of large saccades with long fixations in the direction of the critical ear.

Eye movements are perhaps the most direct indicators of attentional performance. Eye movements and fixations are necessary for the acquisition of required information. They can be used as indicators for each of the dimensions of attentional performance, and changes in movement patterns have been found to be correlated with changes in attentional state related to task demands or to changes in physiological states, such as intoxication or sleep debt. The absence of nominally appropriate eye movements, however, does not indicate inattention. Acquiring and processing eye movement data requires relatively elaborate equipment, and their utility as a basis for an inattention detector is limited. However, eye movements seem to have excellent potential for use in research and development efforts.

### 3.2.2.2 SUBSIDIARY TASK PERFORMANCE

Investigators have shown relatively little interest in the use of extraneous subsidiary task performance as an indicator of inattention. It is a completely ambiguous indicator, since a failure to respond to the secondary task indicates only a failure to allocate effort to the secondary task and attentional performance may be adequte or inadequate. Similarly, good performance on a subsidiary task implies nothing about driving-related attentional performance. The additional task may, in fact, result in inadequate attentional performance related to driving.

Laurell and Lisper (1976), for example, measured driver reaction time to auditory stimuli during extended periods of on-road driving. They found driver reaction time increased during the period, but no changes were found in the reaction times of passengers or subjects seated in a stationary vehicle for the same period of time. Since the same task time was used for all subjects, the authors suggest that the increased driver reaction times were due to perceptual-motor requirements of driving rather than changes in attention with time. Related to this interpretation are the results of a study by Nobel and Sanders (1970). They found that search for critical signs imbedded in groups of signs interfered with performance on a tracking task, and tracking errors increased with search difficulty. Similarly, McDonald and Ellis (1975) and McDonald and Hoffman (1977) found the demand of a secondary task resulted in an increase in steering wheel reversal rate of on-road drivers.

A possibly more useful approach to the application of the concept of subsidiary task performance is to consider measures on different component tasks in driving rather than including extraneous tasks. For example, Moskowitz et al. (1976), Ziedman et al. (1980) and Buikhuisen and Jongman (1972) found that subjects driving simulators while under the influence of alcohol shifted their attention from the roadway to speed control. Reaction time to detection of information signs was inconsistent, but greater time was required to respond to the information, and subjects observed fewer critical incidents. Regina et al. (1974) observed that drivers given caffeine (presumably increasing arousal level) were faster in responding to high beam signals and missed fewer signals than control subjects in an extended duration simulation driving task. Putz (1979), investigating reaction times to peripherally presented visual stimuli when subjects were exposed to carbon monoxide gas, found that the reaction times increased after two hours of exposure, and the increase was faster and greater with higher levels of the gas.

As indicators of inattention, driving-related signal errors and increased reaction time to these signals, for example, are reasonably direct. However, they are not unambiguous and their usefulness as a basis for an inattention detector is limited by the requirement for independent indication of the critical signal. Technically, there are no obstacles to the development of the required signal system. One concept of a system for use in railroad locomotives, for example, requires the engineer to respond correctly to a signal inside the cab when it is triggered by a signal transmitted from a source such as critical speed signal.

### 3.2.2.3 STEERING MOVEMENTS

The results of past research indicate that during long periods of driving, a driver's steering movements become coarse, i.e., the number of large steering movements increases and the number of small movements decreases. In recent investigations, this change in driver control behavior has been found by investigators using a variety of specific steering control measures in both simulator and on-road studies. In addition, recent studies have shown that short-term changes in driver's attention state may be reflected in changes in steering movements. For example, increased steering wheel reversal rate with imposition of a secondary task.

Reporting in general terms, Lemke (1980) noted that during extended periods of driving in a simulator, driver control activity became more coarse; and Allen et al. (1978) observed that the number of critical movements decreased for licensed drivers with repeated showing of a six-minute driving scenario. No such changes were observed in the control behavior of subjects who were non-drivers.

Steering wheel reversal rate, although a coarse measure, has been used in a number of studies. MacDonald et al. (1980) present a good review of the results obtained with this measure. As they indicate, steering wheel reversal rate has been found to increase with increased traffic density (Greenshields, 1963), encounters with oncoming vehicles (Rockwell and Lindsey, 1968), decreased lane width and decreased preview distance (McLean and Hoffman, 1972, 1973), with increased workload (Hecks and Wierwille, 1978), and with drug induced high arousal states (Safford and Rockwell, 1970). Generally, these studies suggest a correlation of greater steering wheel reversal rate with higher workload and high levels of arousal or attention. Completing these results, Mortimer and Sturgis (1979) found the effect of depressant drugs was to reduce the reversal rate. Armour (1978) found the reversal rate was lower for drivers on roads with double center lines. Possibly, this was related to a reduced attentional demand due to the better definition of the center line.

The complexity of the relationship between steering wheel reversal rate and the attentional state of the driver is suggested in two studies by MacDonald and Hoffman (1977, 1978). In the first, conducted on a test track, they found the reversal rate increased with task demand due to extremely narrow lanes, but it decreased with task demands imposed by a secondary task. In the second, on-road, test they found the reversal rate increased with imposition of a secondary task, but was lowest on those sections of the road with the greatest number of events. Considered together, the results of these experiments suggest that the drivers changed their attentional state (re-allocated available capacity) during the most severe test conditions. Thus, reversal rate appears to be sensitive to changes in attentional state and may have potential for indicating transitory changes in the attentional state.

In other analyses of steering behavior, Wierwille (1981) found that during long duration driving periods in a simulator, the number of large steering wheel reversals greater than 72 degrees increased; the number of small reversals from 0.5 to 2.0 degrees decreased; and the mean steering reversal amplitude increased. The standard deviation of the steering wheel position also increased. Ziedman et al. (1980) found that increased driver BAC also resulted in increased steering error and RMS steering error. In detailed analyses of steering performance, McLean and Hoffman (1971, 1972, 1973) found a high correlation between the steering wheel reversal rate and the power in the high frequency (greater than 0.4 Hz) area of the steering spectral density curve. Of general interest, they noted that most drivers exhibit a primary dominant frequency of less than 0.3 Hz in their steering frequency spectrum, and they suggest that the number of reversals between five and seven degrees might be a most useful measure. They also noted the ambiguity in interpreting reversal rate (and other indicators) since, for example, a fatigued driver might tolerate greater steering or vehicle position error, and thus show a low reversal rate; or the fatigue might be shown as a higher rate of reversals because of increased difficulty in maintaining the desired accuracy of steering input.

In related laboratory studies, tracking error has been used by a number of investigators. As would be expected, error has been found to increase during long task periods and with the use of depressants. Putz (1979) scored his subjects on a compensatory tracking task during four hours of continuous exposure at three levels of carbon monoxide: 5, 35, and 75 ppm. He found tracking error for the high frequency input increased in a positively accelerated manner during the exposure period, and the increase was most pronounced with the highest level of the gas. Tracking error for the low frequency input increased only after three hours of exposure. Noble and Sanders (1980) had their subjects search for critical traffic signs imbedded in dense and distributed groups of signs. They found tracking error was the greatest when subjects had to search through distributed groups of signs and increased with the number of critical signs to be detected. As might be expected from classical work on displays, tracking error was least when critical signs were uniquely color coded.

Shinar et al. review the work of Sussman and Morris (1970), and Sugarman and Cozalt (1972) on road position steering movements, as well as that of Riersmesa et al. (1977), Mackie and O'Hanlon (1977), and O'Hanlon and Kelley (1977) on speed variability. As a result of their review, Shinar et al. concluded that studies of driver/vehicle performance have indicated that vehicle lateral road position, steering movements, and vehicle speed increase in variability with alertness decrements and time-at-the-wheel.

3.2.2.3 BRAKE PEDAL ACTIVITY

In recent research, investigators have shown little interest in brake pedal activity as a measure. In the only study found, Konz and MacDonald (1968) used it in their study of the effects of music on driver control activity and found the presence of music had no affect on brake pedal activity.

3.2.2.4 ACCELERATOR PEDAL ACTIVITY

In the study cited above, Konz and McDougal found drivers moved the accelerator pedal more often when listening to music by the Tijuana Brass than when listening to slow music or during silence. Mortimer and Sturgis (1979) reported that drivers under the influence of alcohol showed greater variability in accelerator pedal activity than sober drivers. Lemke (1982) reported that pedal activity of drivers decreased during extended periods of driving. Shinar et al. reviewed work by Riermesa et al. (1977), Mackie and O'Hanlon (1977), O'Hanlon and Kelley (1977), and Sugarman and Cozalt (1972), which showed that in on-road studies, speed variability increases with time in monotonous driving.

Steering movements have been used by many investigators as indicators of inattention. They are directly related to attentional performance, but are ambiguous since "coarse" steering performance, for example, may indicate a decision of an attentive driver as well as inadequate attentional performance. The available data suggests that it may be possible to reduce this ambiguity with the use of complex analysis of scores on several measures of steering wheel activity. These measures have good potential utility as a basis for an inattention detector. In contrast, both accelerator and brake pedal activity appear to be affected by so many personal and environmental factors that they seem to have limited potential for such use. It should be noted, however, that accelerator pedal activity has been used successfully as an element in a statistically derived complex signature used to identify sleepy drivers.

Ziedman et al. (1979) observed increased speed variability and reduced room to spare for emergency stops with subjects driving a simulator under the influence of diazepam or secobarbital. In another simulator study, Freedman et al. (1980) found RMS accelerator error was increased for drivers under the influence of alcohol. Regina et al. (1974), also using a simulator, found that during extended periods of driving, subjects responded more quickly to velocity changes of a lead vehicle, particularly during the second of two 90-minute driving periods, if they were given caffeine. Mortimer and Sturgis (1979) observed that on-road drivers under the influence of alcohol maintained greater headway distances and had greater headway variability than sober drivers. Konz (1968) in his study of the effects of types of music, found faster driving with slow music than with silence or Tijuana Brass, but the number of speed changes was greatest with the Tijuana Brass.

### 3.2.3 VEHICLE DYNAMICS

Measures on vehicle position and heading reflect and compliment measures on driver control behavior. In general, the same comments apply to both sets of measures.

#### 3.2.3.1 LATERAL POSITION

Shinar et al. reviewed the work of Sussman and Morris (1970), and Sugarman and Cozalt (1972). These investigators found, through simulator studies, that road position error increased with driving time. On-road testing replicated their results. These findings have been confirmed in recent investigations. Wierwille (1981) found lateral position variability to increase with time during extended periods of driving in a simulator. Blaauw (1982), comparing data obtained in simulator and on-road driving, found lateral position error and variability greater in simulator driving than in on-road driving. McDonald et al. (1975) found increased lateral drift and lateral acceleration when drivers were asked to perform a secondary task while driving.

Similar results have been obtained with drivers under the influence of depressant drugs. In a study by Ziedman et al. (1979), mean lane position error and lane position variability were increased for subjects driving a simulator under the affects of diazepam or secobarbital.

It appears that measures on lane position error may indicate possible inattention, but they can, of course, also indicate driver reaction to traffic conditions. Triggs (1980), for example, made the observation that vehicles meeting on a two-lane highway systematically moved away from the road centerline.

#### 3.2.3.2 HEADING ERROR OR YAW

Wierwille and Muto (1981) found that both the number of yaw reversals greater than two degrees and the standard deviation of the yaw angle increased during extended periords of driving a simulator. In a comparison of simulator and on-road driving, Blaauw (1982) found the variability of yaw rate was less in a similator than in on-road driving for experienced, but not for inexperienced, drivers.

Measures of driver control activity and vehicle dynamics are perhaps among the most consistent and useful indicators of possible driver inattention. Measurement of lateral position error is usually accomplished with a lane sensing system. The possibility of inferring land drift and change in relative lane position from measures of steering wheel activity, lateral acceleration and yaw rate, for example, should be examined. Measures of vehicle position relative to other vehicles are strongly affected by personal and environmental variables. However, considering the rapid advances in micro-electronics and miniaturized radar systems, they should be considered for use as an element in combined signature systems or for use in stand-alone proximity warning systems.

## 3.3 COMPLEX PERFORMANCE SIGNATURES

Although there are a number of indicators that have potential utility for use in an inattention detection system, they tend to be ambiguous and unreliable when taken singly. 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 induced 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 techniques may be used to determine parameter values or changes which may be used to categorize a driver.

### 3.3.1 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 that 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:

$$\frac{\text{(lateral position standard deviation)} + \text{(mean lateral position)}}{\begin{array}{l}\text{(lateral position} \\ \text{standard deviation)}\end{array} + \begin{array}{c}\text{(steering} \\ \text{wheel} \\ \text{reversals)}\end{array} + \begin{array}{c}\text{(accelerator} \\ \text{pedal} \\ \text{reversals)}\end{array}}$$

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.

### 3.3.2 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 highly 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 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

### 4.1 OBJECTIVE AND INTRODUCTION

In this section we will review the state-of-the-art in driver alertness monitors. There are, at present, a limited number of such devices that are commercially available. These range from the unsophisticated head-droop alarm to the microprocessor-based system of steering wheel driving pattern/driving time patterns that is available in Japan on Nissan's Bluebird line of vehicles. These and several devices that were at one time commercially available, are detailed in Section 4.2.

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, closure rate, etc. These indicators and their potential for development into practical monitors are discussed in Section 4.3.

Although not directly related to driver attention per se, the status of systems related to the vehicle and its environment are considered in Section 4.4. These include radar warning and braking systems, navigational aids, roadside monitors and automated highway systems. These systems could be considered as part of a multi-variate approach in the development of a driver alertness monitor.

The state-of-the-art in automotive electronics will be briefly reviewed in Section 4.5. 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.

### 4.2 DRIVER ALERTNESS SENSORS

Several devices have been developed over the years to monitor driver alertness and to stimulate the driver when his performance degrades due to inattention or drowsiness. Appendix B contains sales brochures and articles on each of the driver alertness indicators. Table 4.1 summarizes these devices.

### 4.2.1 COMMERCIALLY AVAILABLE INDICATORS

Three driver alertness indicators are currently available at the consumer level: the Reli "Stay-A-Wake", the Slarner "Driver Alert Warning Device" and the Nissan "Safety Drive Advisor". The Ford Motor Company's "Owl Driver Alertness Aid" and the Safex "Drive Alert" were marketed several years ago, but are no longer being produced.

#### 4.2.1.1 RELI "STAY-A-WAKE"

The Reli Corporation is based in Markle, IN. Reli has developed the "Stay-A-Wake" alertness alarm that senses the vehicle's speed through a connection to the speedometer cable and monitors steering corrections through an optical sensor tape that is mounted on the steering column. An alarm will sound if no steering motions, whether reversals or advancements, are made within a three to seven second period. The driver selects the appropriate interval by manually adjusting the alarm. Approximately one second after the alarm begins, the cruise control will be defeated and the vehicle's horn will sound. The excess speed function alerts the driver at the selected speed. The alarm increases in intensity if the selected speed is exceeded. The device is powered by the vehicle's electrical system and retails for approximately $170.

#### 4.2.1.2 SLARNER "DRIVER ALERT WARNING DEVICE"

The Slarner "Driver Alert Warning Device" was developed and patented by a French corporation. It is worn on the ear of the driver like a hearing aid and operates with a mercury level switch that is engaged when the driver's head drops below normal, as when the driver begins to nod from drowsiness. The device emits an 86dB alarm at 2000 Hz and is adjustable to 18 pre-selected positions.

## TABLE 4.1. 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. | | |
| Starner "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.

The "Driver Alert Warning Device" is manufactured in the Orient and is being distributed in the United States by the American Automobile Association (AAA) for $33.

4.2.1.3 NISSAN "SAFETY DRIVE ADVISOR"

The Nissan "Safety Drive Advisor" was developed for the NRV-II (Nissan Research Vehicle) and is available on the Nissan "Bluebird", which is being marketed in Japan. The "Safety Drive Advisor" monitors the driver's steering wheel reversal rate and records elapsed driving time.

After two hours of daytime driving, the device sounds a buzzer and lights a display in the form of a coffee cup for approximately ten seconds, advising the driver to take a break from driving. A series of lights are activated, one every 30 minutes, and an alarm will sound every hour for a maximum of three hours, until the driver turns the ignition off or allows the car to stand idling for a period of more than five minutes. The "Driving Time Monitor" function will alert the driver after the next period of driving equal to four times the resting time, and will continue to encourage the driver to rest at this time interval. When the windshield wiper and headlight switches are activated, indicating night driving and adverse weather, the time interval between driver rest warnings is reduced 20%, 10% for each, and the light warning indicators will signal at 25-minute intervals.

The "Safety Drive Advisor" will engage the "Weary Driving Monitor" at vehicle speeds greater than 50 km/hr (approximately 30 mph). The device monitors the driver's normal steering reversal rate for the first ten minutes of driving through a photo-optical steering angle and velocity sensor in the steering wheel. The system monitors the steering pattern and will sound an alarm and light an indicator regardless of elapsed driving time to alert the driver of a decrease in performance. The NRV-II version includes a voice simulator that warns: "You are getting drowsy. Please rest." If the control unit senses brake, turn signal, clutch or gear level actions, the system will disregard steering reversals for a predesignated time interval. The unit identifies a winding road through steering signals and, again, disregards steering motions for a predesignated period.

The development of the "Safety Drive Advisor" has been conducted at Nissan's Central Laboratory over the past ten years. The optical and velocity steering sensor is an integral part of Nissan's electronic power steering system, which is offered on Bluebird models. The unit cost is said to be approximately $85.

### 4.2.2 POTENTIALLY AVAILABLE INDICATORS

Two driver alertness indicators, the Life Technology Inc./Ford "Owl" and the Safex "Drive Alert", are not commercially available at this time.

#### 4.2.2.1 LIFE TECHNOLOGY INC./FORD "OWL"

In the late 1960's, the Ford Motor Company conducted research into driver behavioral patterns, which resulted in the development of an experimental driver attention aid. The device records the driver's steering reversal rate under normal conditions and continually compares that profile to the driver's long-term performance. Life Technology Inc., of Concord, California, was licensed to develop the patented Ford device into a commercially available product.

The "Owl" tracks and records the driver's steering wheel reversal rates for the first three minutes of driving at a speed greater than 35 mph as the standard and compares that profile with continuing driver response. If the reversal rate drops too low, usually indicating inattention, an alarm sounds. If the reversal rate becomes too high, potentially indicating that the driver is going too fast for the road conditions, a light is turned on, cautioning the driver to reduce speed.

Several of the "Owl" devices were manufactured and tested by Ford in the early 1970's. Ford conducted field tests of the "Owl" with a variety of drivers, including truck and bus drivers, race car drivers, astronauts, and drivers selected from the general public. A representative of Ford's Driver Safety Division, who participated in the "Owl" Test Program, stated in a recent telephone conversation that the test drivers eventually tired of the warning system and turned the level control down in order to defeat the system.

#### 4.2.2.2 SAFEX "DRIVE ALERT"

This product was marketed by Safex of Manchester, Connecticut, which is no longer in business. The device is identical in operation to the Slarner "Driver Alert Warning Device", in that it emits an 86dB, 2000 Hz alarm when the mercury level switch engages as the driver's head droops. The "Drive Alert" also is worn on the Driver's ear, and can be set to 18 pre-selected positions. The device weighs less than an ounce, runs on batteries and retails for $30.

## 4.3 POTENTIAL INDICATORS OF DRIVER ALERTNESS

Table 4.2 lists the various physiological and behavioral indicators of inattention, how these indicators are sensed and some of the advantages and disadvantages of the indicators relative to their potential development as a practical monitor of inattention. Many of these indicators have been studied in an attempt to relate them to attention, work load, and vigilance. The status of these research efforts was summarized in Section 3.0 of this report. These indicators have been monitored in both laboratory/simulator experiments and in actual road studies. In general, Table 4.2 indicates that the sensor techniques for monitoring physiological indicators of inattention are obtrusive in nature, may require complicated data handling and would not lend themselves to a near-term, practical driver monitor. However, the informational content of some physiological indicators, such as EEG, may be the best indicators of the driver's state of arousal. For the present, these physiological indicators will continue to be of more value as experimental tools used in a program to develop practical driver attention monitors.

The behavioral indicators offer more immediate promise for adaptation to a practical driver alertness monitor. This is because they generally manifest themselves in a vehicle-related response (operator control performance) and are more adaptable to passive monitoring. These indicators include steering,

## TABLE 4.2. PHYSIOLOGICAL INDICATORS OF DRIVER ATTENTION

| 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<br>Could be made remote by incorporation into steering wheel<br>Easy to interpret | May require detailed spectral analysis<br>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<br>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<br>Relationship to inattention not well established |
| Muscle Electrical Activity | Electrode | Voltage Amplitude and Frequency | P | O | Relatively easy to monitor | Relationship to inattention weak<br>Remote monitoring not possible in near-term |
| Body Activity | Observer or Switches | Number of Movements<br>State Change Frequency | P | R | | Requires observer<br>No established correlation to inattention |
| Respiratory Pattern | Transducer | Frequency | P | O | | Difficult to monitor<br>Correlation with vigilance inconsistent |
| Critical Flicker Frequency | Self-Assessed | Null Frequency | A | R | Easy to administer<br>Could be built into vehicle dashboard | Driver would have to stop vehicle to administer<br>Weak correlation with fatigue |
| Head Nod Angle | Switch | State Change | P | O | Cheap, Commercially Available | Measures last stage of drowsiness |

(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.

## TABLE 4.2 (continued) 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<br>Studied extensively<br>Commercially available | Affected by vehicle/driving environment<br>Individual variations |
| Accelator pedal movement | Linear potentiometer | Rate and amplitude | P | R | Easy to monitor | No established relationship to attention<br>Individual Variations |
| Brake Pedal Movements | Linear potentiometer, pressure transducer | Rate and pressure | P | R | Easy to monitor | No established relationship to attention<br>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<br>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<br>Can be made remote | Interpretation difficult<br>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<br>Usually Tracking | | A | R | Can be a simple device | Distracts from main task |

accelerator, brake, shift, and clutch control as well as vehicle heading. These indicators can be sensed using existing, relatively simple technology and require no action on the part of the driver outside of normal driving activities. In fact, these indicators, except for head noding, are the ones usually adapted for the commercial market (see Section 4.2). Other behavioral indicators of inattention, such as eye movements and vehicle closure rates, can be monitored but require more sophisticated technology. For instance, Honeywell has developed the oculometer-type device that remotely monitors eye movement over a wide-range of head movement. This device has been used in both simulator and real-world vehicle experiments. Lane drift and measurement of vehicle closure rates also require sophisticated technologies that could include radar, sonar, and optical tracking devices, roadside lane monitors with appropriate vehicle sensors, and extremely sensitive on-board guidance systems, either inertial or satellite based. Devices operating on these principles are discussed in Section 4.4. The costs, reliability, and practicality may preclude the use of such systems in the near-term.

None of the presently available or potential indicators of inattention can, individually, be considered the ideal alertness monitor. We recommend that the most fruitful approach would lie in the development of a multi-variate behavioral system similar to Nissan's.

## 4.4 OTHER RELATED MONITORS

This section will briefly review the status of systems available to complement the development of driver alertness monitors. These systems include radar sensing (warning and braking), roadside monitors, navigational aids and automated guidance highways.

### 4.4.1 RADAR SENSING

Radar sensing can be used to alert the driver of an impending unsafe condition or to actually apply the vehicles brakes. In a review of these systems performed for NHTSA in 1981 by Kinetic Research Inc. ("Collision Avoidance System Cost

Benefit Analysis"), ten collision avoidance systems were identified as functional or under development. The manufacturing companies were American, European, and Japanese. Kinetic Research concluded that radar braking systems would be more effective in avoiding accidents than simple warning devices. They would be most effective in reducing rear impact collisions (a reduction in accidents of 26% to 62%) and least effective in reducing side collisions (a reduction in accidents of 3% to 4%). The ultimate costs of such systems were difficult to calculate, but they concluded that the costs and benefits would be equal, based on 1979 dollars. False alarms were difficult to quantify and were of concern. No time-frame for incorporation into the vehicle fleet was considered.

With respect to vehicle closure rates, one of the features of Nissan's NRV-II safety vehicle was a radar auto-cruise (see Appendix). With the vehicle operating under cruise control, the radar senses the distance to the vehicle in front and displays this information along with the calculated safe distance. The system warns the driver and de-activates the cruise-control if the NRV-II comes too close to the vehicle in front. The cost of such a system is not given.

### 4.4.2 NAVIGATIONAL AIDS

Navigational aids are available in several commercially marketed vehicles in Japan. Such systems have been developed by Nissan, Toyota, and Honda. Ford is developing a system in the U.S., as is Volkswagen-Siemens in Germany. Honda's system is the most sophisticated and is available on the Japanese Accord-equivalent for $1300. The device works on a gas-tube "gyro" system. Although its location accuracy is not given, the device has problems sensing minor directional changes such as those encountered on multi-lane highways. Ford Motor Company's navigational system will locate a vehicle within 1200 feet by satellite guidance. The VW-Siemens system uses an on-board magnetic field sensor, the vehicle's longitudinal axis, and speedometer distance pulses to compute and display a vehicle's direction and distance to destination. In addition, the system uses infrared transmitters on traffic lights to tell the driver how best to reach their required destination (such a concept could also be used as a driver warning response system similar to that used on trains, where the train operator is required to perform a specific function such as pressing a button when given a certain cue).

Toyota also has available a sonar-based back-up warning system. These devices are viewed as indicators of the state of vehicle technology, and in the long term, as part of an integrated multi-variate crash avoidance system.

### 4.4.3 AUTOMATED HIGHWAY SYSTEMS

The ultimate technique for overcoming driver inattention is to remove the driver completely from the system. This can be accomplished by an automated highway. In a 1982 study performed for the FHWA ("Systems Studies of Automated Highway Systems"), the various candidate system concepts were evaluated for application in the 1990 to 2000 time-frame. The study results recommended a system with an "intelligent" vehicle (radar and electronically equipped) with a self-contained power supply (engine) operating on a passive guideway. They estimated that, if development and testing started in 1982, the prototype system would be completed in 1995 and a "Phase 2" urban system in 2010. In our estimation, it would appear that the automated highway system could have no major impact on highway safety before the middle of the 21st century.

## 4.5 AUTOMOTIVE ELECTRONICS

Electronics for automobiles has taken a tremendous leap forward in the past ten years. This progress was driven by the need for engine control microprocessor systems for improved fuel economy, greater performance, and improved emission control. The cost of the electronics contained in the average U.S. vehicle increased from $25 to $250 between 1970 and 1980, and could reach as high as $1400 by 1990. Sixteen bit microprocessors with 2MHz frequency will soon be available with programmable memories. Voice synthesis and driver visual aids are available and will be expanded in the near future. Voice recognition and synthesis will contribute to a safer driving environment by allowing the driver to concentrate on road conditions. An important next step in automotive electronic development will be the use of multiplexed systems and fiber optics to eliminate complex wiring. Such an advancement will allow the easy addition of extra electronic equipment (such as aftermarket driver monitors). The existing electronic systems and the near-term projected advancements lead us to conclude that the electronics will be available to reliably track and analyze any practical driver alertness monitor.

## 5.0 CONCLUSIONS

The material reviewed in this document indicates the following:

### 5.1 ACCIDENT DATA

- The fact that a large portion (38%) 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.

### 5.2 RESEARCH FINDINGS

- Changes in performance associated with task duration and 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.

- 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 discriminating the effects of these changes from those imposed by the driving environment.

## 5.3 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 a secondary task are likely to be distracting to the driver and, therefore, potentially hazardous.

- A driver attention indicator must be able to "learn" the shape of the performance change curves particular to the individual driver.

- Of the proprietary devices reviewed, only the Nissan Safety Drive Alert System, which is based on a multivariable analysis approach and learns the patterns of the individual driver, represents a potentially promising approach.

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

## 6.0 RECOMMENDATIONS

Based on the material reviewed to date, it is concluded that a research effort to experimentally investigate the efficacy of a multivariate technique for monitoring driver attention should be undertaken. The results of this preliminary study have shown that a significant number of vehicular accidents are associated with the failure of the driver to respond to external stimuli, indicating reduced alertness. A research effort is proposed to identify and determine the most effective techniques for monitoring driver attention and advising the driver of critical degradations in attentional state.

The research program would require both a laboratory simulation phase and a field testing phase. The laboratory testing would involve the use of "part-task-simulation." The purpose would be to investigate idiosyncratic changes in driver performance as a function of attentional state. The results of the laboratory testing will provide a basis for the development of performance criteria which can be evaluated under real-world conditions in the field testing phase.

### 6.1 SIMULATION PHASE

The purpose of this phase will be to develop a set of descriptive metrics for changes in performance associated with:

- Time-on-task,
- Sleep deprivation,
- Task requirements, and
- Stimulus environment complexity.

In this phase, subjects (stratified by age and sex) would be trained on compensatory tracking tasks. Performance would be evaluated in terms of response frequency, consistency, and accuracy. Subjects would be trained on the tasks until a performance plateau was reached and then tested repeatedly to determine criteria for measuring performance changes due to attentional lapses. These changes would be correlated with physiological indices of attention such as EEG and eye movement patterns.

## 6.2 FIELD TEST PHASE

If criteria for evaluating performance shifts within individuals are successfully developed, then these criteria would be evaluated and validated through on-road testing. Road testing would be required for the following reasons:

- Only those performances that are integral parts of the driving task, such as steering, braking, and velocity control can be used. The addition of other tasks which require frequent responses could be distractive and thereby hazardous.

- Tests to evaluate and validate measures of attentional change must occur in a naturalistic environment with appropriate visual, auditory, and motion cues. There exist no simulation facilities that can provide the required environments.

- The evaluation and validation of the measures must be imbedded in other credible road testing efforts, such as tire testing or vehicle testing, to minimize the possibility of the driver's attentional state being influenced by the attentional testing itself.

- The field testing will be an iterative development/evaluation effort, rather than a series of classic experiments.

- Field testing would provide an opportunity for evaluating proprietary devices.

## APPENDIX A

## 1982 NASS DATA TABLES

**TABLE 1. ALL COLLISION ACCIDENTS – 11,868 ACCIDENT CASES**

| RELATED FACTORS | | DISTRIBUTION OF ACCIDENTS | % |
|---|---|---|---|
| DRIVER AGE..... | UNDER 25 | 4296 | 36 |
| | 25 TO 55 | 5961 | 50 |
| | OVER 55 | 1611 | 14 |
| LAND USE...... | URBAN | 9238 | 78 |
| | RURAL | 2629 | 22 |
| TIME PERIOD... | EARLY AM | 1594 | 13 |
| | AM RUSH | 1634 | 14 |
| | MID-DAY | 3908 | 33 |
| | PM RUSH | 2341 | 20 |
| | EVENING | 2314 | 20 |
| ROAD.......... | STRAIGHT | 9750 | 82 |
| | CURVED | 2089 | 18 |
| NUMBER OF OCCUPANTS... | ONE | 8071 | 68 |
| | 2 OR MORE | 3797 | 32 |

**TABLE 1.1. DRIVER RESPONSES IN ALL COLLISION ACCIDENTS**

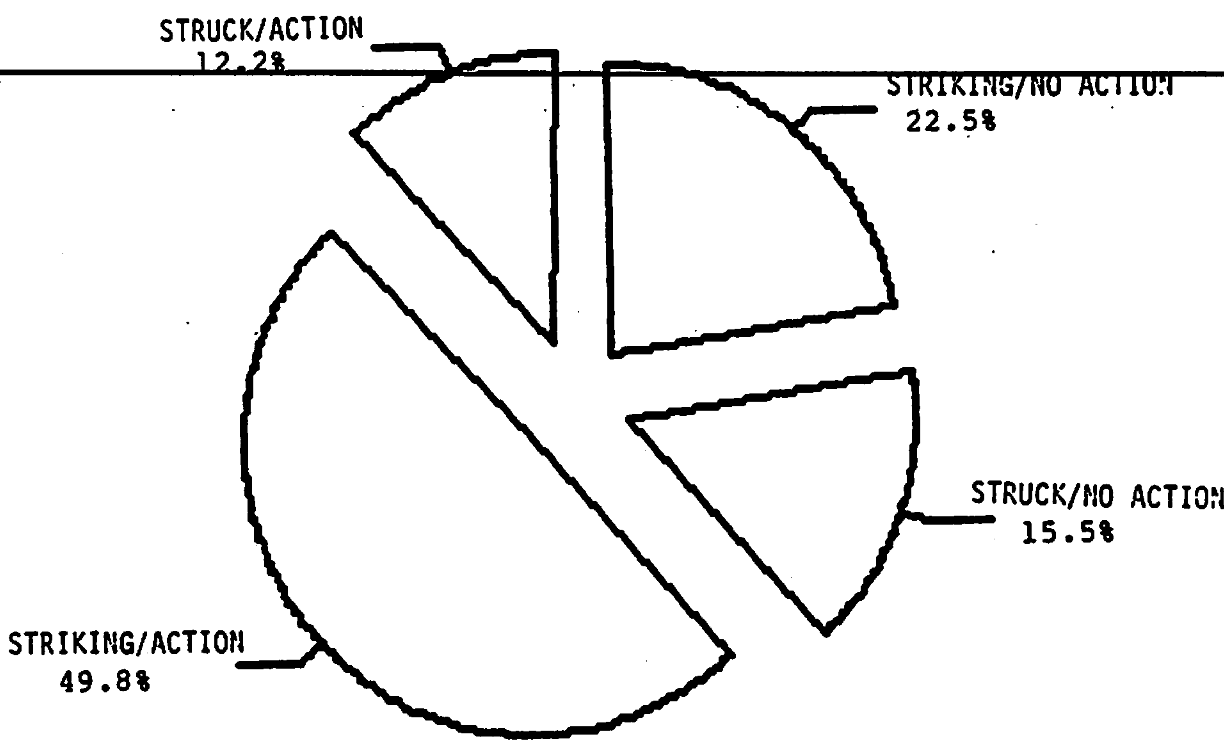


**TABLE 2. SINGLE VEHICLE ACCIDENTS AS A PERCENTAGE OF ALL COLLISION ACCIDENTS***

**SINGLE VEHICLE ACCIDENTS = 3,142 OF 11,868 ACCIDENT CASES**

| | | SINGLE VEHICLE ACCIDENTS | % | % OF ALL COLLISION ACCIDENTS | ALL COLLISION ACCIDENTS | % |
|---|---|---|---|---|---|---|
| DRIVER ACTION..... | UNDER 25 | 1442 | 46 | 12 | 4296 | 36 |
| | 25 TO 55 | 1379 | 44 | 12 | 5961 | 50 |
| | OVER 55 | 321 | 10 | 3 | 1611 | 14 |
| LAND USE........... | URBAN | 2129 | 68 | 18 | 9238 | 78 |
| | RURAL | 1012 | 32 | 9 | 2629 | 22 |
| TIME PERIOD....... | AM RUSH | 322 | 10 | 3 | 1594 | 13 |
| | MID-DAY | 682 | 22 | 6 | 1634 | 14 |
| | PM RUSH | 467 | 15 | 4 | 3908 | 33 |
| | EVENING | 786 | 25 | 7 | 2341 | 20 |
| | EARLY AM | 838 | 27 | 7 | 2314 | 19 |
| ROAD ALIGNMENT.... | STRAIGHT | 2308 | 73 | 19 | 9750 | 82 |
| | CURVED | 830 | 26 | 7 | 2089 | 18 |
| NUMBER OF......... OCCUPANTS | ONE | 2215 | 70 | 19 | 8071 | 68 |
| | 2 OR MORE | 927 | 30 | 8 | 3797 | 32 |

*NOTE: ALL COLLISION ACCIDENTS' represents both striking and struck vehicles. Both a vehicle striking another vehicle and a vehicle striking a roadside object are considered STRIKING vehicles.
A STRUCK vehicle in a single vehicle accident would have been hit by something other than another vehicle (such as roadside debris).
Therefore, SINGLE vehicle accidents are a subset of ALL COLLISION ACCIDENTS.
A SINGLE vehicle accident represents an accident in which only one vehicle was present.
See definition of 'Vehicle Role' on p.6 for further explanation.

**TABLE 3. ACCIDENTS ATTRIBUTABLE TO INATTENTION**

**946 OF 11,868 ACCIDENT CASES**

| | | DISTRIBUTION OF ACCIDENTS | % |
|---|---|---|---|
| AGE........... | UNDER 25 | 381 | 40 |
| | 25 TO 55 | 444 | 46 |
| | OVER 55 | 121 | 12 |
| LAND USE...... | URBAN | 676 | 71 |
| | RURAL | 270 | 28 |
| TIME PERIOD... | AM RUSH | 146 | 16 |
| | MID-DAY | 277 | 31 |
| | PM RUSH | 150 | 17 |
| | EVENING | 182 | 20 |
| | EARLY AM | 121 | 13 |
| ROAD.......... | STRAIGHT | 745 | 85 |
| | CURVED | 137 | 15 |
| NUMBER OF OCCUPANTS... | ONE | 629 | 71 |
| | 2 OR MORE | 255 | 29 |

**TABLE 3.1. ACCIDENTS ATTRIBUTABLE TO INATTENTION**

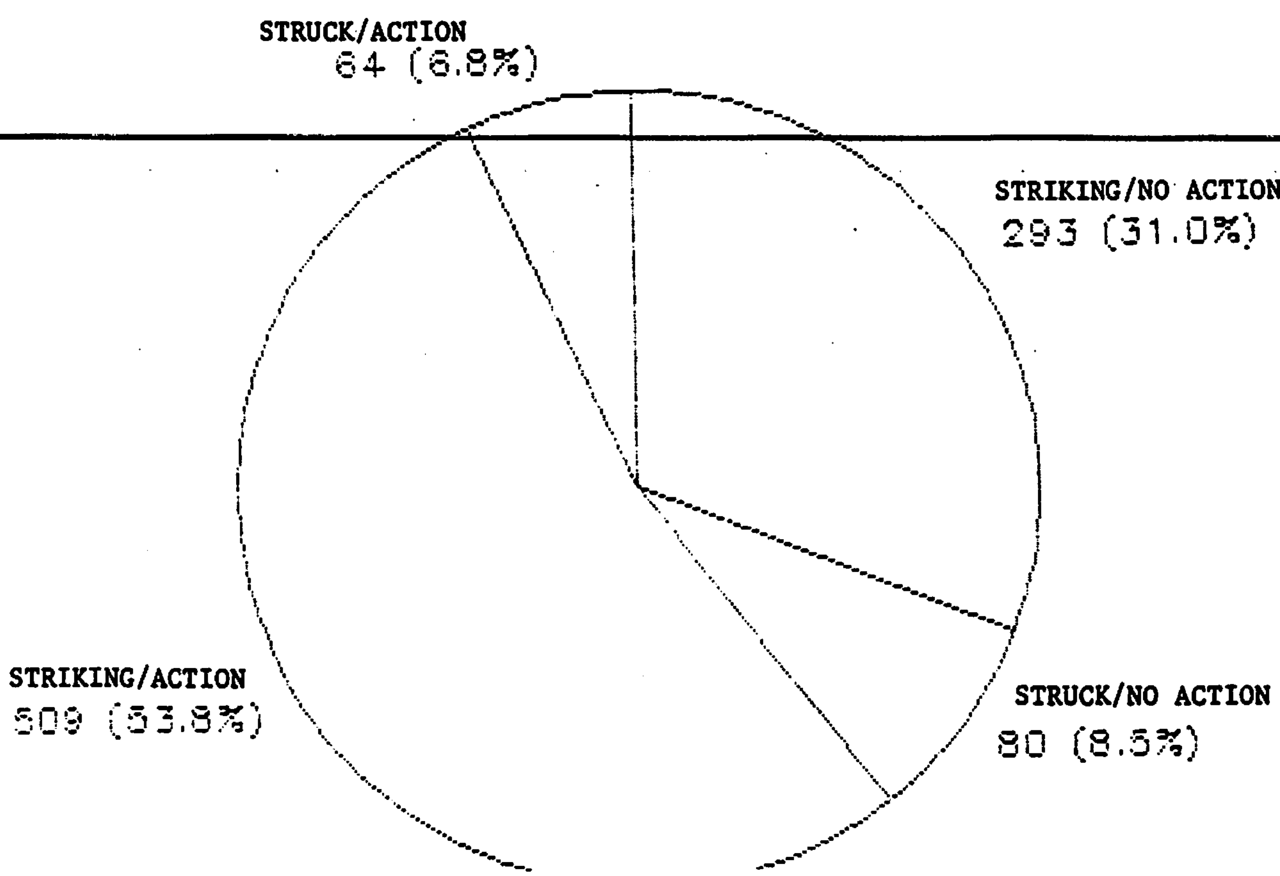


**TABLE 4. ACCIDENTS ATTRIBUTABLE TO DROWSINESS**

**176 OF 11,868 ACCIDENT CASES**

| | | DISTRIBUTION OF ACCIDENTS | % |
|---|---|---|---|
| AGE............ | UNDER 25 | 92 | 52 |
| | 25 TO 55 | 73 | 41 |
| | OVER 55 | 11 | 6 |
| LAND USE....... | URBAN | 83 | 47 |
| | RURAL | 93 | 53 |
| TIME PERIOD.... | AM RUSH | 29 | 16 |
| | MID-DAY | 11 | 6 |
| | PM RUSH | 11 | 6 |
| | EVENING | 21 | 12 |
| | EARLY AM | 103 | 59 |
| ROAD........... | STRAIGHT | 129 | 73 |
| | CURVED | 47 | 27 |

**TABLE 4.1. ACCIDENTS ATTRIBUTABLE TO DROWSINESS**

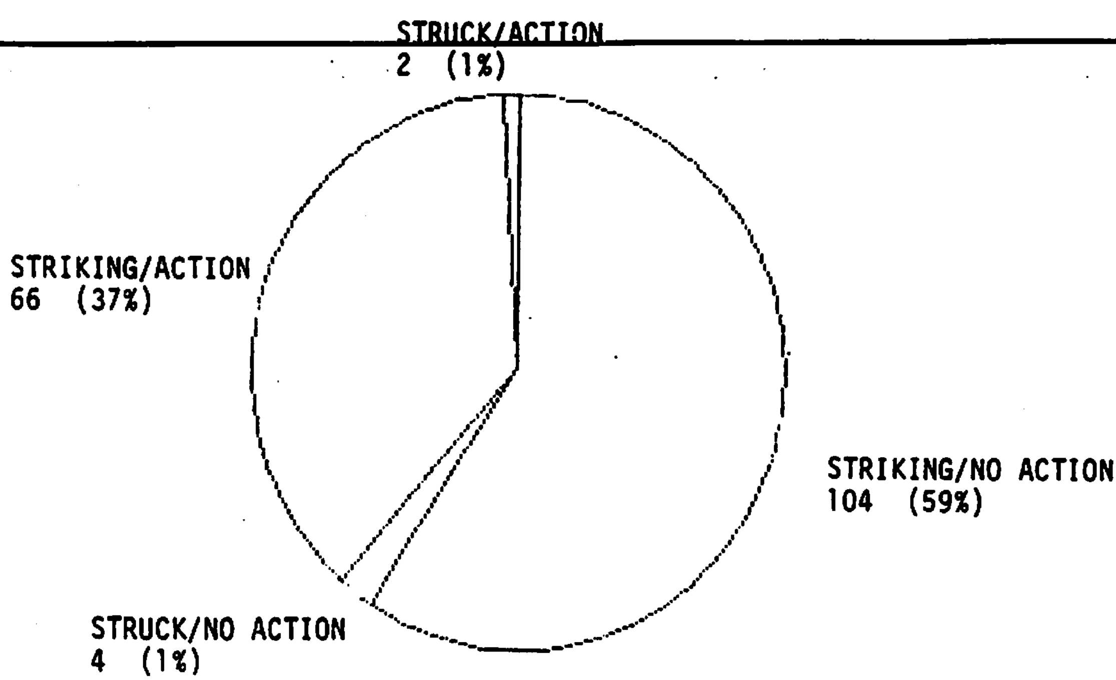


**TABLE 5. ACCIDENTS ATTRIBUTABLE TO DRUNK DRIVERS (BAC LESS THAN .07%)**

**376 OF 11,868 ACCIDENT CASES**

| | | DISTRIBUTION OF ACCIDENTS | % |
|---|---|---|---|
| AGE........... | UNDER 25 | 152 | 40 |
| | 25 TO 55 | 200 | 53 |
| | OVER 55 | 24 | 6 |
| LAND USE...... | URBAN | 245 | 65 |
| | RURAL | 131 | 34 |
| TIME PERIOD... | AM RUSH | 4 | 1 |
| | MID-DAY | 24 | 6 |
| | PM RUSH | 44 | 11 |
| | EVENING | 130 | 35 |

**TABLE 5.1. ACCIDENTS ATTRIBUTABLE TO DRUNK DRIVERS (BAC LESS THAN .07%)**

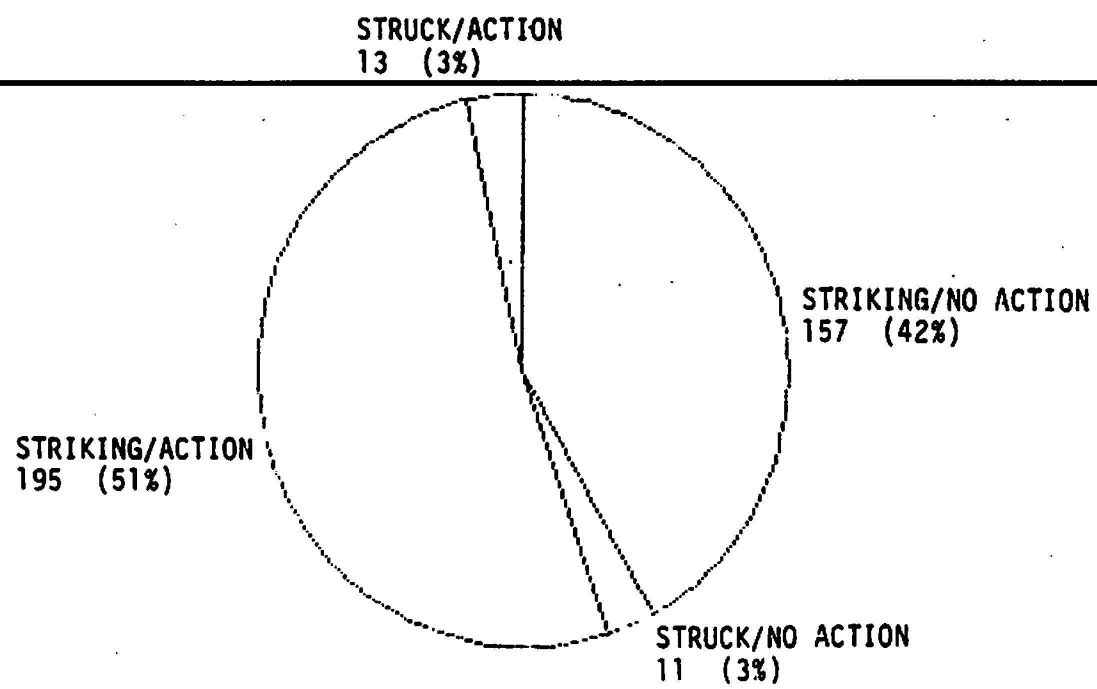


TABLE 6. ACCIDENTS ATTRIBUTABLE TO INATTENTION (1982 NASS)

946 OF 11,868 ACCIDENT CASES

| DRIVER AGE | AVOIDANCE ACTION | % | NO AVOIDANCE ACTION | % |
|---|---|---|---|---|
| UNDER 25 | 244 | 43 | 137 | 37 |
| 25 TO 55 | 271 | 47 | 173 | 46 |
| OVER 55 | 58 | 10 | 63 | 17 |
| | ---- | --- | ---- | --- |
| TOTAL = | 573 | 100 | 373 | 100 |

## TABLE 7. ACCIDENTS ATTRIBUTABLE TO INATTENTION (1982 NASS)

### 946 OF 11,868 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 |

**TABLE 8. ACCIDENTS ATTRIBUTABLE TO DROWSINESS (1982 NASS)**

**176 OF 11,868 ACCIDENT CASES**

| TIME OF DAY | AVOIDANCE ACTION | % | NO AVOIDANCE ACTION | % |
|---|---|---|---|---|
| AM RUSH | 8 | 12 | 21 | 19 |
| MID-DAY | 6 | 9 | 5 | 5 |
| PM RUSH | 5 | 8 | 6 | 6 |
| EVENING | 9 | 14 | 12 | 11 |
| EARLY AM | 38 | 57 | 65 | 59 |
| | ----- | --- | ----- | --- |
| TOTAL = | 66 | 100 | 109 | 100 |

TABLE 9. ACCIDENTS ATTRIBUTABLE TO DROWSINES (1982 NASS)

176 OF 11,868 ACCIDENT CASES

| NUMBER OF OCCUPANTS | AVOIDANCE ACTION | % | NO AVOIDANCE ACTION | % |
|---|---|---|---|---|
| ONE | 48 | 75 | 91 | 84 |
| MORE THAN ONE | 16 | 25 | 17 | 16 |

# APPENDIX B

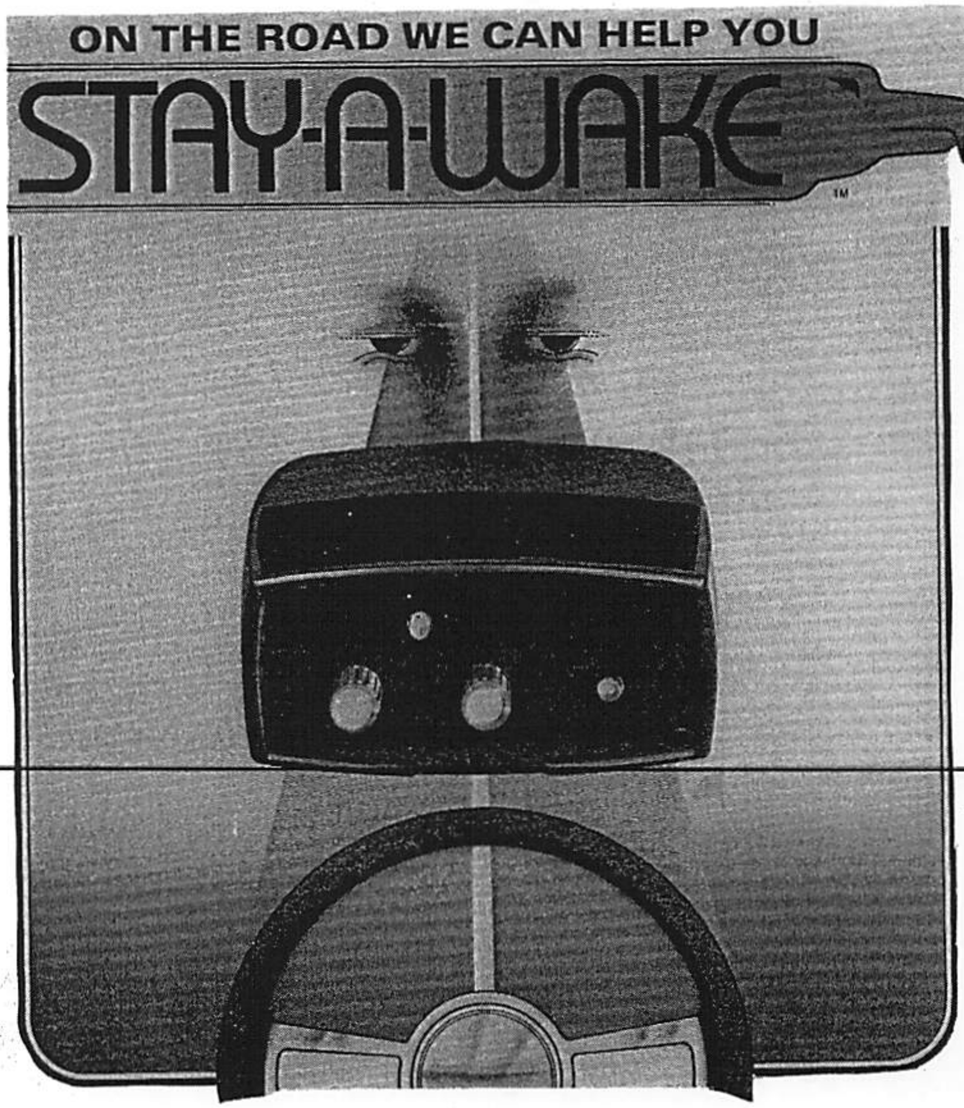
## ALERTNESS INDICATORS

There have been several devices developed as indicators of driver alertness. The following brochures depict the operation of the:

1. Reli "Stay-A-Wake"
2. Slarner "Driving Alert Warning Device"
3. Nissan "Safety Drive Advisor"
   - SAE article
   - Japanese journal article
   - NRV-II
4. Life Technology Inc./Ford "Owl"
5. Safex "Drive Alert"

Appendix B (Con't)

Reli "Stay-A-Wake"



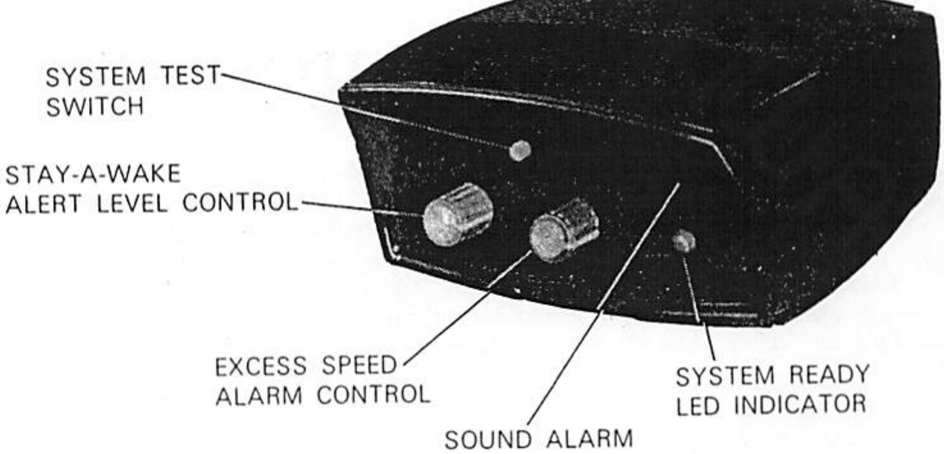
# STAY-A-WAKE

## ELECTRONIC SAFETY COMPANION THAT NEVER SLEEPS!

Stay-A-Wake electronically monitors driver alertness along with vehicle speed and "sounds off" when conditions are unsafe. Driver alertness is determined by sensing steering corrections, comparing these corrections at the vehicles speed over a preset time period. Normal steering corrections required for proper and safe vehicle control provides an excellent indicator of driver alertness. Altered or sudden changes in steering corrections, preceed and can forewarn driver drowsiness, sleepiness or road hypnosis due to prolonged driving.

## STAY-A-WAKE FEATURES:

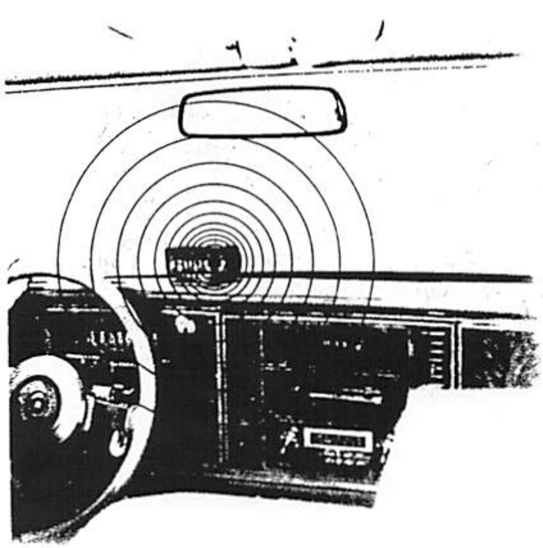
- Detects driver sleepiness
- Warns against excessive speeds
- Attention getting warning alarm
- Fully automatic, adjusting required alertness at driving speed
- Test switch for system check out
- System functioning L.E.D. Indicator
- Adjustable alertness level for varying driving and road conditions
- Remote switching output for Cruise Control (defeats upon alarm)
- Optical steering correction sensor (no mechanical steering wheel contact)
- Velcro hook and loop fastener for dashboard mounting
- Solid state integrated circuit reliability
- Simple to use — Easy to install
- Universal — Will work with all American made vehicles and most foreign models




Stay-A-Wake a fully automatic safety alarm actuates itself at 15 MPH and constantly monitors your driving alertness by analyzing steering corrections at the vehicles speed over a preset time interval. Once the level of desired driver alertness is programmed into the Stay-A-Wake alarm any reduction in driver alertness will signal the alarm to "sound off" and defeat the Cruise Control if interconnected.

Another safety monitoring feature of the Stay-A-Wake is an excess-over-speed alarm which alerts the driver when the preset maximum speed has been exceeded.

Stay-A-Wake alertness level along with maximum vehicle speed alarms are easily adjustable and can be set to accommodate all driving and highway conditions — no annoying nuisance false alarms. Each alarm can be independently adjusted and turned off if desired.



Stay-A-Wake alarm is complete with system test switch which permits total system check out prior to actual driving. A solid state L.E.D. light comes on when the Stay-A-Wake is functional and monitoring driver alertness. Stay-A-Wake automatically adjusts the level of driver alertness required for safe driving at all vehicle speeds above 15 MPH.

PATENT PENDING

## LIABILITY STATEMENT:

Stay-A-Wake is designed and manufactured as a safety alarm to be used by the vehicle operator at their discretion to aid driver alertness. Reli Corporation assumes no responsibility or liability for the driver, passengers, vehicle or property associated with the Stay-A-Wake alarm. This product in no way relieves or reduces the responsibility of the driver to maintain his powered vehicle under safe and proper control during all conditions.

## LIMITED WARRANTY STATEMENT:

We guarantee our equipment when properly installed to be free from defect in material and workmanship under normal use and service, and we will, within 90 days from delivery to original purchase, repair or replace without cost to the owner, any part or portion thereof which our inspection proves to be defective (if and when returned to us) with proof of purchase – within 90 days to: Reli Corp., P.O. Box 393, Markle, Indiana 46729, or any Reli Corp. authorized factory service center, transportation charges prepaid and only defective unit returned.

This guarantee does not apply to equipment which has been subjected to misuse, neglect, accident, or exposure to the elements, and is in lieu of all guarantees expressed or implied, and we do not authorize any person or representative to assume for us any other liabilities with our products.

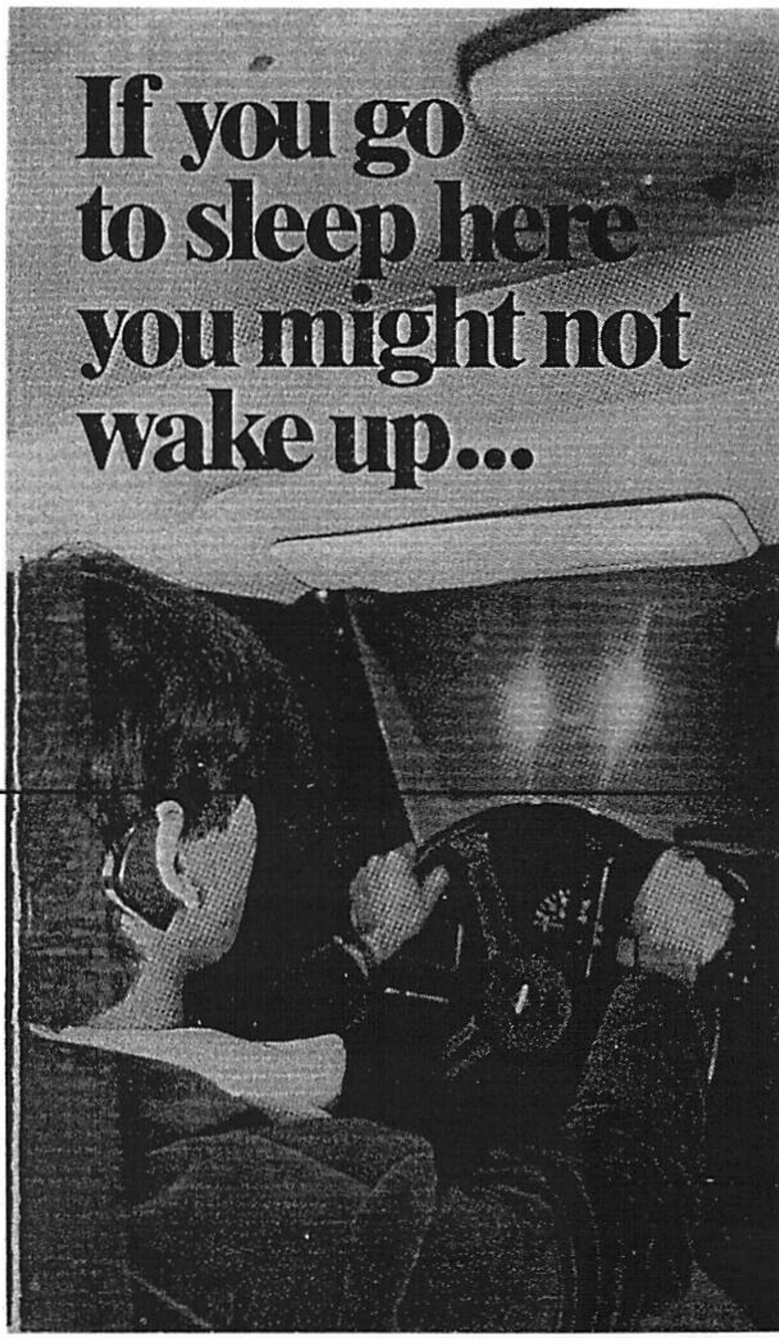
Reli Corporation expressly disclaims any express or implied warranties or liabilities that its equipment will be fit for any particular purpose and any other expressed or implied warranties or liabilities other than those specifically set forth herein, including without limitation any warranty or merchantability.

Unless installation instructions are followed exactly, the manufacturer will not be responsible for damage or defect.

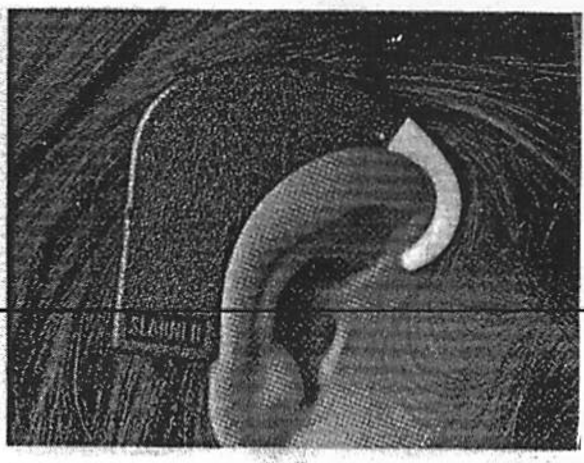

STAY-A-WAKE
RELI CORPORATION
P. O. BOX 393
MARKLE, IN 46770

Appendix B (Con't)

Slarner "Driver Alert Warning Device"



# Guard against falling asleep at the wheel with AAA's Driver Alert Warning Device!




**AAA Driver Alert Warning Device (3682)**
Help guard against falling asleep at the wheel with AAA's new Driver Alert Warning device. The Driver Alert is designed to signal an individual that they have started to dose off—rest is needed—it's dangerous to continue driving.

The shape of this durable, lightweight (15 grams including the 1.5V battery) device provides comfort and ensures transmission and amplification of an 86 decibel, 2000 hertz frequency alarm when any of its 18 pre-selected positions is surpassed by a nod of the driver's head.

Designed to accommodate all ear contours, the Driver Alert can be worn on either ear regardless of whether you wear glasses or not. The device comes in a convenient storage box with adhesive backing for quick and easy mounting on your car's dashboard.

**A $32.95 Value!**

**AAA member price only $21.00 each, or 2 for $40.95. Non-members add $5.00 per warning device.**

# AAA's Driver Alert Warning Device!

- Comfortable
- Durable, lightweight
- 86 decibel, 2000 hertz frequency alarm
- Accommodates all ear contours
- Fits either ear, with or without glasses
- Adhesive backing for mounting on your dashboard

Appendix B (Con't)

Nissan "Safety Drive Advisor"*

## Onboard electronic adviser warns of erratic steering behavior

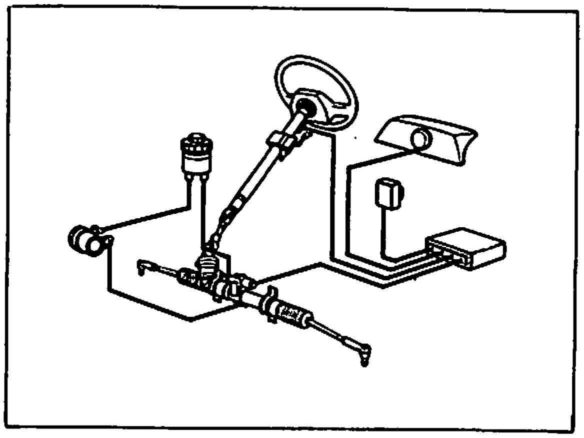
SDA, safety drive adviser, is one of many electronic devices Nissan had built into its experimental safety vehicle, the NRV (Nissan Research Vehicle), which are now being offered on top models in the recently updated Bluebird mid-size car range. SDA, as first introduced in the NRV, had a singular function of warning the driver of erratic steering behavior. To this, Nissan has added a timing device that displays an elapsed driving time by a row of incremental lamps, and advises of a timely stretch-out break by lighting up a "coffee cup" display lamp and sounding a buzzer, which the system judges at two hours after departure on a clear daylight condition. Should the driver ignore the advice, and push on, the system issues a buzzer warning every hour thereafter. If the driver heeds to the system's wisdom, it allows four times the actual rest time (ignition key off, or the car stays stationary with the engine running for more than five minutes) to the next increment of elapsed driving time, delaying advice time. For night driving and inclement weather with wipers on, the system shortens information and advice intervals, for each deducting ten per cent. So driving in rain at night, the system issues a "better-take-a-cup" advice at one hour 36 minutes plus ATD.


**Safety Drive Adviser** advises of elapsed driving time by a row of lamps, and at two hours plus, recommends that the driver rests with a cup of coffee or tea. Its more important and immiment task is to memorize the driver's normal steering habits, and detect any erratic behavior such as encountered when he/she should fall asleep. Then it issues warning by lighting up the cup lamp and sounding alarm buzzer.

SDA's more important and imminent preventive function is its perception of erratic steering behaviors such as when the driver becomes drowsy, or falls in a short but dangerous lapse into sleep, and it emits visual and sound warning. The SDA CPU studies and memorizes the driver's normal steering habits in about ten minutes after his/her start-out (no one is likely to fall asleep during this CPU learning period). Input source is the photo-optical steering angle and velocity sensor built into the steering wheel, which is a component part of EPS, or electronic power steering offered in upper Bluebird models. Erratic steering behaviors that are typical of driver fatigue or drowsiness, as defined by Nissan, are more frequent steering

**Nissan's popular** mid-size car, the Bluebird, goes transverse engine and front wheel drive.

*This is a copy of an article from the January 1984 SAE Automotive Engineering.



Bluebird power steering has adjustable power assist in three settings. Steering is electronically controlled, ensures progressive assistance.

maneuvers, and no steering correction for a prolonged period followed by a jerky motion, the latter being repeated in a drowsy state. The system regards such driver actions as braking, declutching, gearshifting, and putting turn indicators on as normal and conscious, and discounts any steering motions during these maneuvers from its judgement. It, too, considers steering behaviors on cornering as conscious efforts, however spirited they may be, and does not read steering signals for a pre-determined time period.

The basic SDA steering behavior warning function has been in development for more than ten years at Nissan's Central Laboratory. No price has been revealed as the system is offered in a deluxe package on certain top Bluebird models; however, a Nissan spokesman hinted a unit cost of no more than $85, inclusive of the incremental timing device feature.

The car, series U11 Bluebird, which looks outwardly quite similar to its conventional predecessor, has joined Nissan's fast expanding transverse engine, front wheel drive brigade. For the Japanese and most of export markets, the car is powered by lightweight, compact inline four cylinder engines in 1.6 through two-liter capacities, with outputs ranging from the base 1.6's 90 to a fuel injected, turbocharged 1.8's 135 hp JIS. There is also a two-liter diesel version. All gasoline engines employ Nissan's twin-plug fastburn combustion system, in conjunction with catalytic convertors to meet Japan's stringent emission standards. The US model, soon to replace the current inline six powered Maxima sedan, will be a stretched version powered by a new overhead camshaft V-6, again placed sideways.

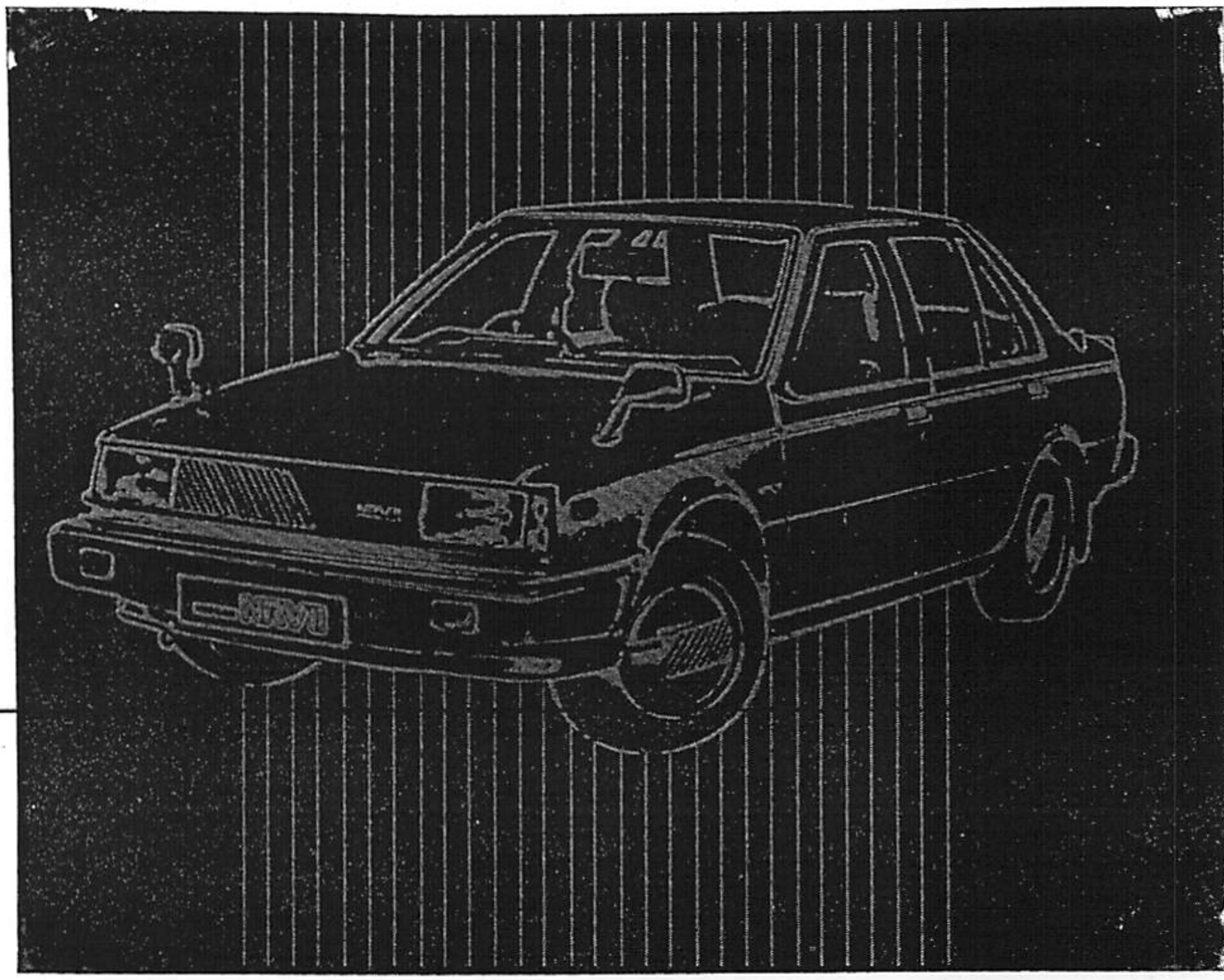
For the new Bluebird, Nissan has developed a new inline automatic transaxle, incorporating a torque converter with top-gear lockup and four-speed planetary gearbox. Driveshafts are of equal length with provision of a central support bearing, to preclude torque steer on take-off. Suspension is all independent by MacPherson struts, the front pair located by pressed L-shape lower arms, and the rear ones by twin parallel transverse links and single trailing links. Variable shock absorbers are available on upper models, that will have three settings the driver can choose, Soft, Normal, and Firm. Likewise, optional EPS has three power assist modes in steering efforts that the driver may choose by a switch. Basic steering is by rack and pinion.

Japanese Journal Article

An excerpt is available of an article printed in Japanese with an English translation describing details of Safety Drive Advisor. Requests for this article may be forwarded to the U.S. Department of Transportation, Transportation Systems Center, DTS-45, Kendall Square, Cambridge, MA 02142.

Appendix B (Con't)

NRV-II
Nissan Research Vehicle



# *NRV-II···NOT SO MUCH AN EXPERIMENT AS A CAR FOR TOMORROW*

*The NRV-II Nissan Research Vehicle is a working example of Nissan's ideas for the car of the future. A future of diminishing energy resources and an ever increasing traffic population, with its attendant needs of greater active and passive safety. The NRV-II meets this future with advanced but practical technology, much of which is already well on the way to production reality. Advanced composite materials are used for weight reductions, and a turbocharged methanol fueled spark ignition engine has been adopted to extract the maximum power (and hence efficiency) from a given displacement, while also paving the way for the use of alternative fuels. Safety in the NRV-II means both passive safety in terms of maximized occupant protection, and active safety, which is achieved by equipping the car with a variety of systems designed to keep the car out of accident situations, and to make the driver's task as simple as possible.*

*To emphasize the practicality of the many ideas incorporated, the NRV-II is based on the Nissan Sunny, Nissan's top selling small family car. The Sunny was selected to give the research team the opportunity to demonstrate the possibilities for producing an ideal "car of the future" within limited external dimensions. The NRV-II measures a compact 4185 mm long by 1620 mm wide, the same as the Sunny. And in spite of the many safety devices incorporated and substantial side protection in the doors, the only interior sacrifice has been a mere 6 cm reduction in interior width. Further, thanks to the advanced lightweight materials used throughout the car, a fully equipped production version of the NRV-II would weigh only about 70 kg more than the equivalent Sunny.*

*The practicality of the NRV-II is further enhanced with a high performance 1.3 litre methanol fueled turbocharged engine that puts the NRV-II in a performance league with a superior two litre car. Maximum power output is 120 bhp at 6,000 rpm, which gives the NRV-II acceleration that takes it from 0 to 100 km/h in just 7.7 seconds.*

*With performance, convenience and safety, the NRV-II is much more than just an experiment. It is truly a car for tomorrow.*

# FEATURES OF THE NRV-II

Methanol Fueled Turbocharged Engine
Plastic Fuel Tank
Plastic Road Wheels
Plastic Windscreen and Window

## SAFETY

■ REDUCED DRIVER WORKLOAD

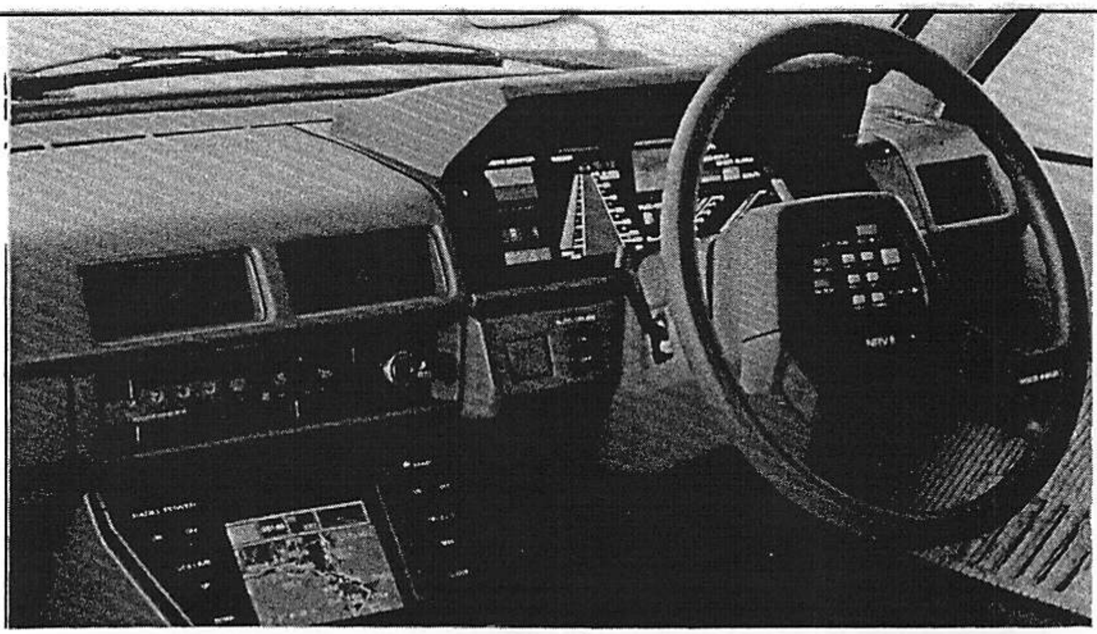
Radar Auto-Cruise
Multi-Colour LCD Instrument Display
Fibre Optics/Steering Wheel
Mounted Switches
Voice Dialogue System
Drive Information System
Automatic Light Switching
Automatic Windscreen Wipers
Variable Tension Seat Belts

■ ACCIDENT AVOIDANCE

Runflat Tyres
Tyre Pressure Warning Device
Drowsiness Monitor
Four-Wheel Anti-Skid System

OCCUPANT PROTECTION

Designing for Protection in Side Collisions



# ENERGY CONSERVATION & WEIGHT REDUCTIONS

## Methanol Fueled Turbocharged Engine

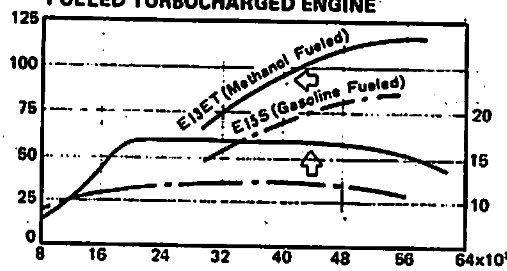
Powering the NRV-II is a small-displacement (1270 cc) spark ignition engine with ECCS controlled fuel injection and a turbocharger, and adapted to run on methanol fuel. Methanol is one of the leading alternatives to gasoline as a fuel for automobiles, and may be derived from coal, of which large unmined reserves are known to exist. It is now relatively more costly to produce methanol than gasoline, but with oil supplies becoming increasingly scarce, the attractions of methanol are growing, and it may well be a major fuel as soon as the early 1990s.

Methanol also has the advantage over gasoline in a spark ignited engine that it diminates knocking, allowing a virtually free choice of compression ratio. In the NRV-II, a ratio of 11:1 has been combined with a turbocharger running with 400mm (Hg) of maximum boost for a high specific output power and optimum economy, while requiring only minor internal changes to the engine. For the future, advances in engine materials and design will allow higher compression ratios, and hence even greater specific outputs.

A high compression ratio also means excellent drivability, eliminating one of the weak points of a low compression ratio gasoline fueled turbocharged engine. The turbocharger itself is conventional, raising both torque and horsepower across the engine speed range, and in particular the torque curve is flat from 1,600rpm to 5,600rpm.

The chief problem currently associated with methanol concerns low temperature starting performance, as methanol will not atomize below 60°. The engine of the NRV-II is equipped with an electric fuel pre-heater.

FULL LOAD PERFORMANCE OF METHANOL FUELED TURBOCHARGED ENGINE




## Plastic Fuel Tank

A 40% weight reduction, worth 4.8 kg in the NRV-II, has been achieved by replacing the conventional steel fuel tank with one that is made of blow-molded plastic. In addition to saving weight, the plastic fuel tank is molded as an integrated whole, and so does not require a flange for joining the upper and lower halves, allowing the maximum use to be made of the available space. In the NRV-II, this has allowed an 8% increase in capacity. Further, the formability of plastic means that odd shapes can easily be produced, allowing every cubic inch of space to be exploited.

To eliminate the problems of fuel permeation, and fuel loss thereby, normally associated with plastic containers, the fuel tank of the NRV-II is formed of a special multi-laminar plastic lined with a barrier resin that is totally impervious to the fuel tank's contents.

## Plastic Road Wheels

The NRV-II is fitted with experimental 13 inch fibre-reinforced plastic wheels. These bring savings of 12.5 kg per car compared with a set of four equivalent steel wheels, or 8 kg per car if the comparison is with aluminium alloy wheels. Reduced weight means better fuel economy, while the lower unsprung mass permits better wheel control for superior handling and greater ride comfort. In addition the use of plastic gives the designer virtual freedom with regard to wheel design, and even wheel colour.

Further wheel related weight savings have been achieved in the NRV-II by the use of run-flat tyres that allow the spare wheel to be dispensed with.

## Plastic Windscreen and Window

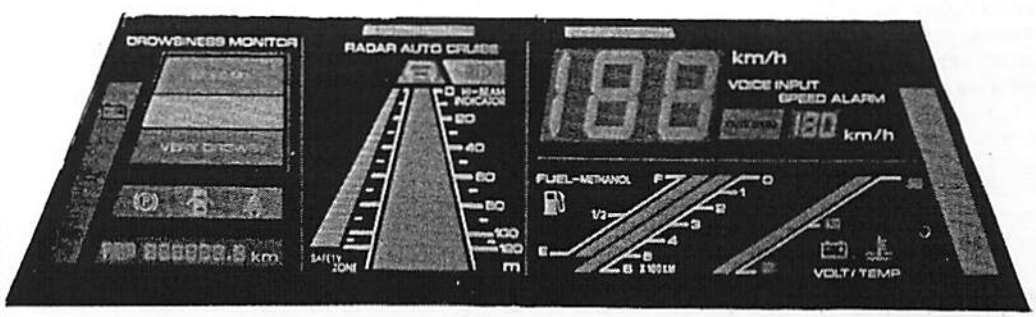
A large proportion of the weight of a car's bodyshell is accounted for by the glass windows. In the NRV-II, a polycarbonite resin windscreen and windows have been used, to save 8.5kg—a 30% reduction. The resin surface has been treated with a hardener to ensure resistance to damage by windscreen wipers, etc.

# SAFETY

## Multi-Colour LCD Instrument Display

The NRV-II's instrumentation consists of three large liquid crystal panels (LCDs) which cover 22 items ranging from a large digital speed readout to displays for the radar auto-cruise and the drowsiness monitor. To greatly aid identifiability, so that display information can be absorbed at a glance, the instrument displays are provided with colour coding, with the instrument light source filtered with four different colours (red, blue, green, and yellow).

The light source itself is a flat flourescent lamp that provides better light distribution and hence superior colour uniformity than conventional light sources. In addition, to ensure visibility in all levels of ambient lighting, the brightness of the instrument display may be adjusted automatically, or manually.




## Fibre Optics/Steering Wheel Mounted Switches

Frequently used switches for the radio, auto-cruise, etc., are mounted on an elegant non-rotating pad in the centre of the steering wheel, where they are located for the greatest ease of access.

These switches and most of the electrical items throughout the car are interconnected by means of optical fibre which allow greater signal density than ordinary metal wiring, while the efficiency of transmission is also improved.

A multiplex transmission system is employed, with the optical fibres arranged in dual loops, for two-way transmission and an emergency back-up for reliability, with no weight penalty.

# SAFETY

## REDUCED DRIVER WORKLOAD

### Radar Auto-Cruise

Auto-cruise speed setting devices are gaining increasing popularity around the world as speed restrictions and the desire to drive economically increase the desirability of maintaining a steady cruising speed on the highway. With existing auto-cruise devices, however, there is no means for automatically responding to the presence of other vehicles.

The NRV-II is equipped with a 24 GHz radar that measures the distance to the vehicle in front, and displays the distance on a coloured graphic display on the NRV-II's instrument panel. In addition, a reference bar alongside the actual distance display indicates the calculated safe following distance, calculated in accordance with the NRV-II's speed and the prevailing weather conditions (a rain sensor is fitted to the windscreen in connection with the automatic windscreen wipers (see below)). In addition to displaying this information, if the NRV-II comes too close to the vehicle in front, a verbal warning alerts the driver and simultaneously interrupts the auto-cruise function to decelerate to the speed of the vehicle in front, in order to maintain a safe following distance. When the vehicle in front moves out the way, or accelerates out of range, the device automatically causes the NRV-II to resume the previously set cruising speed.

RADAR AUTO-CRUISE DEVICE

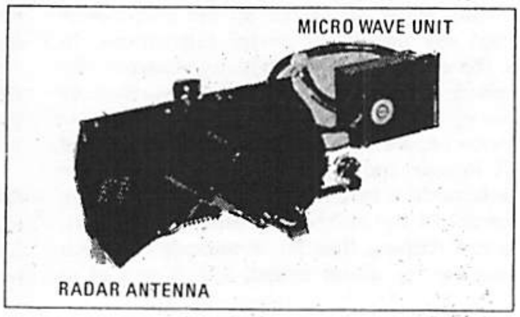
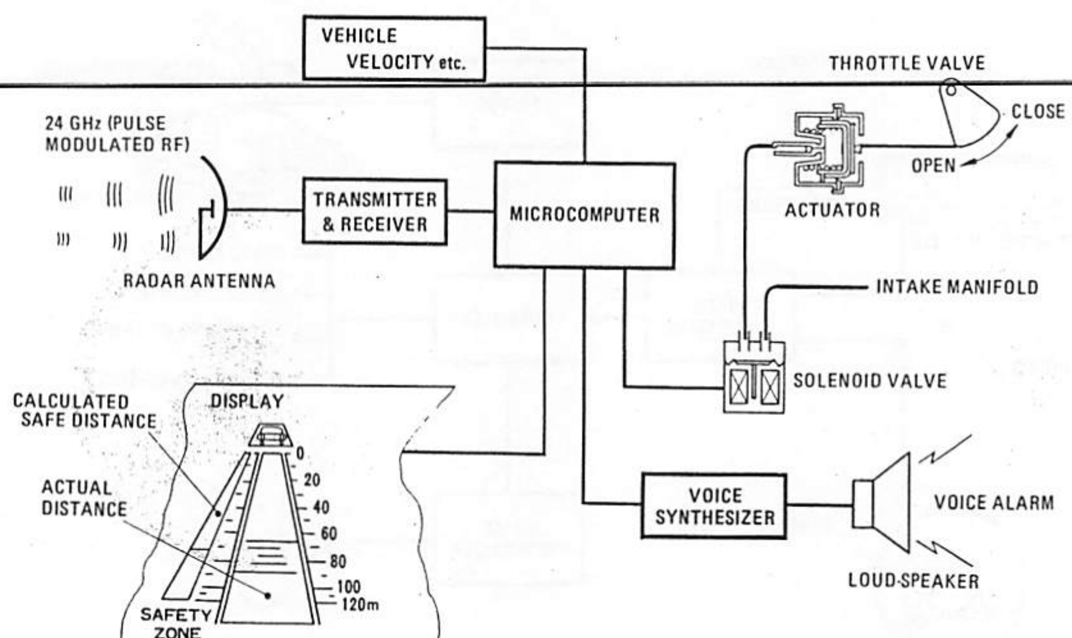



Fig. 1
RADAR AUTO-CRUISE DEVICE



# SAFETY

## ● Voice Dialogue System

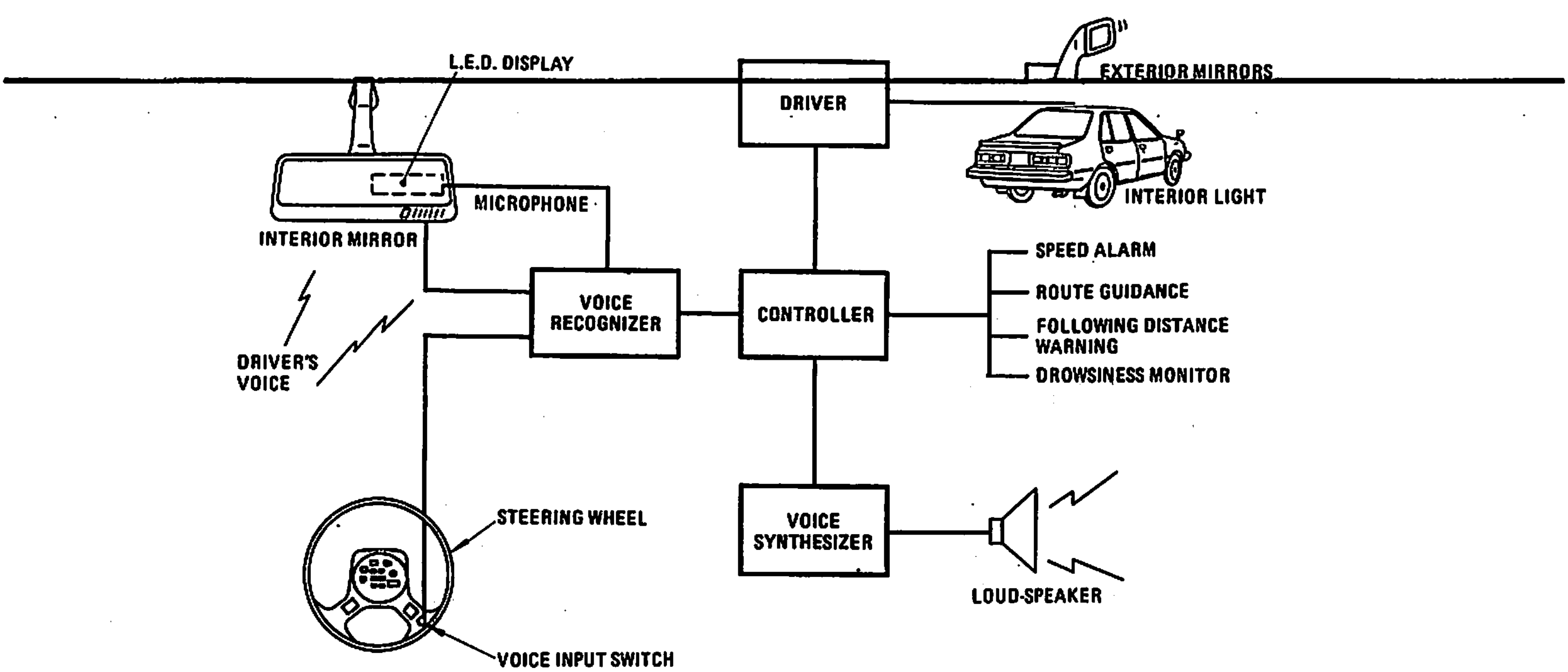
With the increasing volume of traffic on today's roads, the driver cannot afford to take his eyes off the road and his hands off the wheel. Thus to allow the driver to maintain his primary obligation, without missing important vehicle related information or having to do without control of certain vehicular functions, the NRV-II is equipped with a comprehensive voice dialogue system that allows the driver to interface verbally with his vehicle.

The driver simply presses a conveniently located "Voice Input Switch" on one spoke of the steering wheel, to switch on the microphone to accept any one of 26 verbal instructions. In return, the computer replies with an electronically synthesized voice which can issue instructions or warnings up to 50 seconds long.

Voice operated vehicle functions in the NRV-II include the input of route data for the drive information system, speed warning settings, and control of the exterior mirrors, interior light, and hazard flashers. The 26 commands may each comprise any repeatable sound, and so may be in any language, but a user must be registered with the system beforehand by running through the functions in sequence and recording his desired command for each specific function. Subsequent repetition of any of the commands by the registered user will be reliably identified by means of pattern matching with a filter bank, and the corresponding function will be automatically performed. For the registration process, the functions (and suggested commands) are spelled out on an LED display built into one corner of the interior mirror. Included in the commands are 8 possible directions of movement for the exterior mirrors and route guidance cursor, "stop", "clear", "faster", "slower", "advance", "return", 5 speed alarm settings, right or left exterior mirror selection, "interior light", "hazard flashers", "yes", "no", and "acknowledged".

The voice synthesizer that responds to the driver's commands also gives its own verbal warnings about driver drowsiness, insufficient distance from a vehicle in front, and route instructions (e.g. "Right turn ahead").

Fig. 2
VOICE DIALOGUE SYSTEM



# SAFETY

## Drive Information System

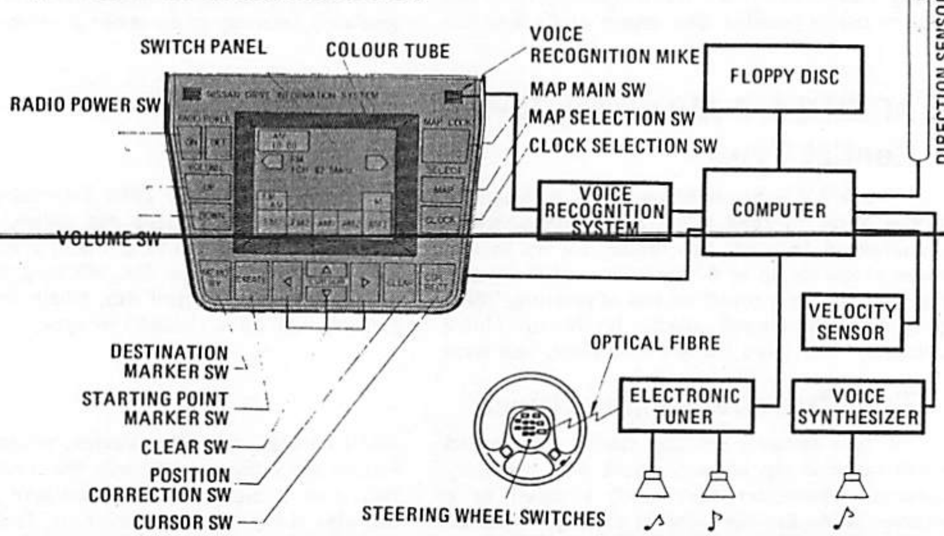
The NRV-II features a drive information system with a colour CRT to selectively display route maps, the time and date, malfunction warnings, and radio tuning information. In addition, the CRT is overlaid with a transparent switch matrix for a number of switching functions with a large touch target area. Switching is achieved by touching the relevant portion of the screen, as indicated by the display information, which may be changed to allow switch area to serve several alternative functions.

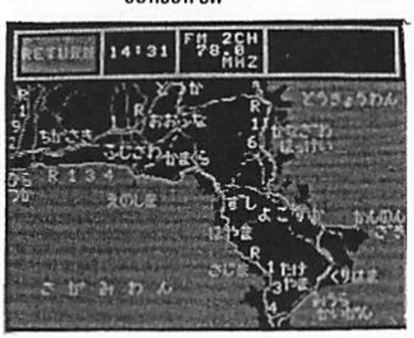
The principal feature of the drive information system is a route guidance system with a store of map information on a mini-floppy disc, which can be scanned and displayed in two scales on the screen. The driver designates his(her) present position by means of the cursor switches. A prospective route may be input verbally. Once on the move, the computer keeps the driver informed with verbal instructions (e.g. "right turn ahead") issued via the voice synthesizer.

The NRV-II's position in relation to the map, and a trace of the route actually travelled are indicated on screen. These are determined by a magnetic direction sensor and a distance recorder

Another function of the Drive Information System is to flash malfunction warnings on screen in the event of any problem. Such warnings automatically displace the existing screen information until the driver acknowledges the message. Once acknowledged, the display reverts to its previous function, and the warning is reproduced in miniature at the top right hand corner of the screen until remedial action is taken.

**Fig. 3 DRIVE INFORMATION SYSTEM**




MAP DISPLAY


RADIO CONTROL PANEL

# SAFETY

## Automatic Light Switching

The NRV-II is equipped with an automatic light switching system that automatically controls the car's head and tail lights in accordance with ambient lighting conditions. Ambient lighting is detected by means of photosensors mounted on top of the dashboard, and when the vehicle is running the lights are switched on or off accordingly. The headlights are also automatically switched off within 3 to 5 seconds each time the vehicle comes to a halt, to save energy and prevent dazzle while waiting at traffic lights, etc., and are switched on again as soon as the vehicle starts moving.

Manual switching of the lights is also possible.

## Automatic Windscreen Wipers

The NRV-II is equipped with an automatic windscreen wiper system which optically detects raindrops on the windscreen and automatically starts or stops the wipers, and adjusts the wiping interval or speed in accordance with the amount of rain. Light is projected from inside the windscreen by light emitting diodes, and the presence or absence of rain on the windscreen is detected by light receptors which are sensitive to the light reflected from the front surface of the glass, and identify any sudden changes in the amount of light reflected such as are caused by the appearance of raindrops on the windscreen.

## Variable Tension Seat Belts

To encourage their regular use, the seat belts in the NRV-II have been made as comfortable and easy to use as possible. The degree of slack in the belts is electronically controlled to be ideal, in accordance with vehicle speed, with the slack being gradually taken up as the speed increases.

# ACCIDENT AVOIDANCE

## Runflat Tyres

The NRV-II has been equipped with special runflat tyres of steel radial construction, which are designed to allow safe driving for up to two hours at speeds up to 80 km/h even after a puncture resulting in a complete loss of pressure. These tyres were developed jointly by Nissan Motor Company and Toyo Rubber Company, and were put on sale in January 1982 for vehicles used by handicapped persons and the police. Secondary tyre beads are used to keep the tyre from coming off the rim after going flat, allowing the use of a conventional type wheel rim, which has not been possible with other runflat tyre types.

## Tyre Pressure Warning Device

A tyre pressure warning device is mounted inside the hub cap of each wheel, with a battery operated transmitter that sends a signal to a receiver inside the car to warn of a tyre pressure having fallen below a preset minimum safe level, due to leaks, etc.. This device, which sounds a buzzer inside the car, not only warns of punctures, but, since it monitors the actual tyre pressure, it can also aid reduced tyre wear and fuel consumption by warning of low tyre pressures.

## Drowsiness Monitor

One of the NRV-II's most innovative features is a unique drowsiness monitor which detects decreased driver alertness and urges him to rest. In the development of this system, a physiological evaluation was made of brain wave patterns and associated physical behaviour, such as eye blinking. From this it was learned to assess the degree of drowsiness, and hence observe the associated patterns of physical manipulation of the vehicle's controls, such as the steering wheel. As installed in the NRV-II, the drowsiness monitor constantly monitors the driver's operation of the controls, and when any change of behaviour suggesting drowsiness is noted, the driver is alerted by means of a flashing light and a buzzer. If the driver continues to exhibit signs of increasing drowsiness, the warning light flashes and a voice warns "You are getting drowsy. Please rest."

# SAFETY

## Four-Wheel Anti-Skid System

One of the major safety developments of the eighties is the four-wheel anti-skid system that electronically controls the braking pressure to all four wheels to prevent skid-inducing lock-up. This contributes greatly to safety as it allows full braking to be used at any time—on curves, slippery surfaces, etc., without any loss of directional control.

In addition, since the anti-skid system prevents wheel lock-up on all surfaces, it satisfies the conditions for maintaining friction between the tyre and the road surface at the optimum level, ensuring the shortest possible braking distances, for an extra margin of safety.

## OCCUPANT PROTECTION

### Designing for Protection in Side Collisions

Designing automobiles to protect their occupants in the event of a collision is one of the most difficult, and at the same time one of the most important tasks facing today's automotive engineers. Considerable attention has been paid in the past to energy absorption in head-on and nose-to-tail collisions which constitute a high proportion of all serious accidents. However, it has begun to be realised that the occupant fatality rate is probably higher in accidents involving side collisions with penetration through the relatively narrow sides of the car. Further, while it is not too difficult to design the relatively long front and rear extremities of the bodywork to absorb collision energy, this task is not nearly so easy when dealing with the relatively thin sides.

The US government's National Highway Traffic Safety Administration (NHTSA) is conducting a study of protection during collisions from the side as a matter of priority in its long-range safety programme. Nissan, too, has attached considerable importance to this area of vehicular safety, and in the NRV-II, the target has been to combine a high level of safety with the practicality that is necessary to make the concept viable for production.

**• PROTECTION STANDARD**

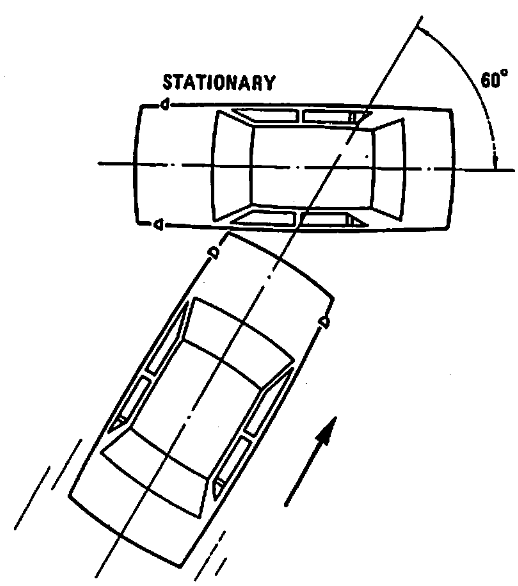
In designing a car for protection, one can only establish arbitrary standards based on repeatable experiments. This does not make the protection offered any less secure, but it does indicate the difficulty of ensuring absolute protection under all circumstances.

For the NRV-II the design brief was for occupant safety in a collision where a stationary vehicle is struck by a 2500 pound (1100 kg) vehicle travelling at 30 mph (48.6 km/h), at 60° to the stationary vehicle's longitudinal axis, as shown in figure 4.

**• PROTECTIVE MEASURES**

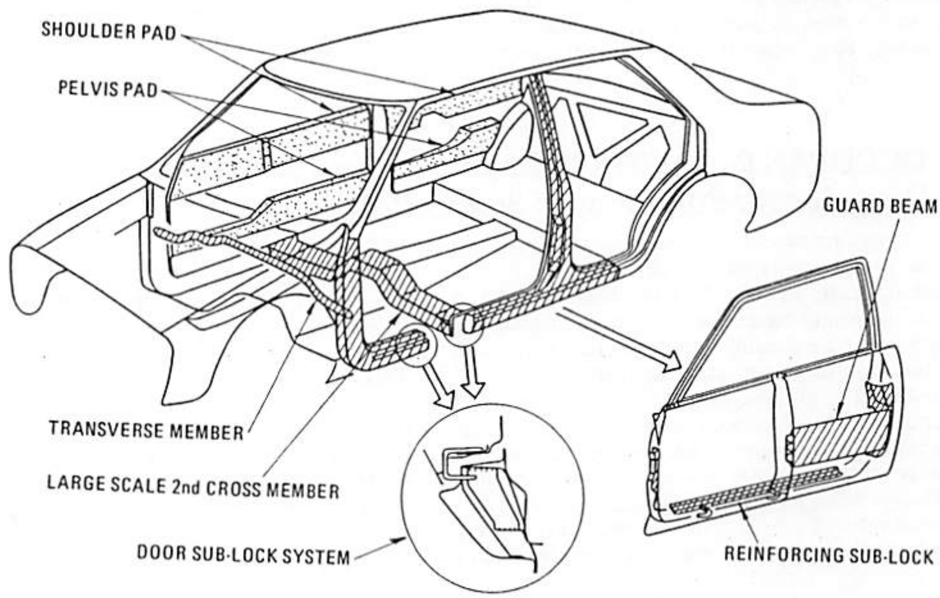
- Door reinforcement
- Reinforcing door sub-locks
- Sill and floor reinforcement
- A and B-pillar reinforcement
- Protective pads on the interior surfaces of the doors

Fig. 4
CONFIGURATION OF SIDE COLLISION TEST



# SAFETY

Fig. 5
SIDE COLLISION PROTECTION




**NRV-II – MAIN SPECIFICATIONS**

| | |
|---|---|
| Length | 4185 mm |
| Width | 1620 mm |
| Height | 1390 mm |
| Interior Length* | 1835 mm |
| Interior Width* | 1305 mm |
| Wheelbase | 2400 mm |
| Suspension Front | Independent struts, coils |
| Rear | Independent trailing arms, coils |
| Tyres | Runflat Tyres 165/70SR 13 |

* Measured to JIS measurement standards.

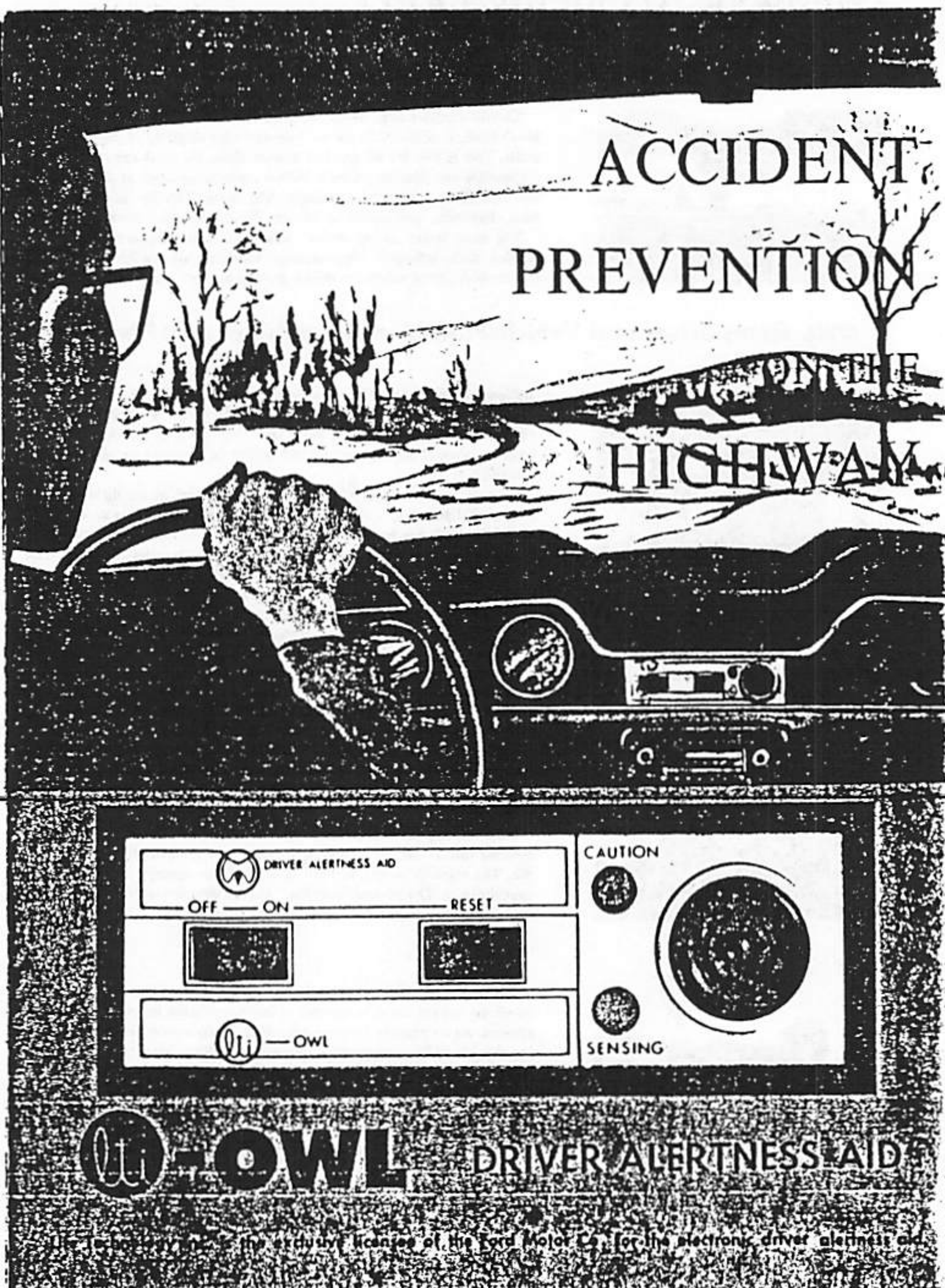
**METHANOL FUELED TURBOCHARGED ENGINE – SPECIFICATIONS**

| | |
|---|---|
| Denomination | E13ET (ECCS) |
| Displacement | 1270 cc |
| Bore X Stroke | 76mm x 70mm |
| Compression Ratio | 11.0:1 |
| Turbocharger Max. Boost Pressure | 400 mm (Hg) |
| Fuel | Methanol |
| Maximum Power | 120 bhp/ 6,000 rpm (JIS) |
| Maximum Torque | 17.0 kgm/ 3,600 rpm (JIS) |

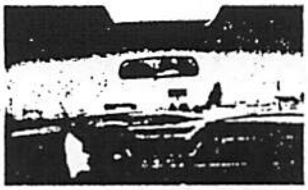
Acceleration 0 – 100 km/h. . . . . . . . . 7.7 seconds

Appendix B (Con't)

Life Technology Inc./Ford "Owl"



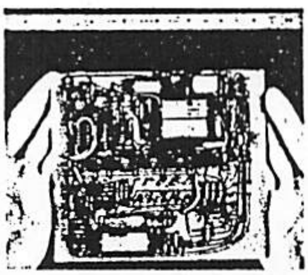
# Highway Accidents Don't ..."Just Happen"



Careful analysis over many years shows that driving error, not vehicle breakdown, is responsible for the overwhelming majority of highway accidents. This is true for all types of drivers. Even the most experienced and responsible can suddenly awake from a momentary lapse at the wheel to find himself in a hazardous situation. The cause? Usually fatigue, drowsiness, hypnosis, preoccupation or—in the other case—driving too fast.

Yet most in-cab safety devices now in use or proposed—seat belts, padded dash, inflatable bags—assume accidents are inevitable, and are therefore designed solely for driver protection after impact.

## OWL Gives Driver and Vehicle Protection Through Accident Prevention

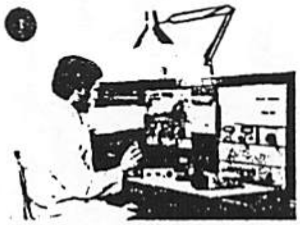


Now comes a completely new concept in highway safety — the OWL Driver Alertness Aid. The OWL is an electronic computer and warning device that alerts the driver when he has drifted too far from his normal driving pattern and before he becomes another accident statistic.

Devices similar to the OWL are standard in the flight decks of commercial airliners; why not in the cabs of highway vehicles as well? The main drawback has been cost and size. Until the advent of the small computer, size and cost would have been impossible obstacles, but solid state integrated circuits have made the OWL technically feasible and economically within the range of most drivers. Further, the dependability and shock resistance of these circuits makes the OWL as reliable as your car radio which means an absolute minimum of maintenance.

Ford researchers, who did the early work in this field, reasoned that if they could somehow "profile" a driver — that is, establish his normal driving pattern—they could use this information on long distance trips by continually comparing his road performance against it, warning the driver when deviations from the normal were leading him into dangerous highway situations.

After testing thousands of drivers they established the steering wheel reversal rate as the most accurate measure of a driver's "tracking" or profile. The research people at Ford developed this concept into an excellent experimental "Driver Attention Aid," but the device was manually adjusted and rather complicated for everyday use by all types of drivers.

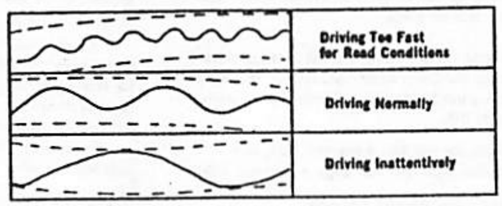


Life Technology Inc. is a California corporation that has been directing its efforts toward the development of instrumentation for preventive health systems. As a company they are interested in products dedicated to extending the life of the individual. Although they have been concentrating on medical instrumentation, they realize that their goal toward life preservation can also be met by developing equipment for preventing death on the highway. Therefore, Life Technology Inc. entered into an exclusive license agreement with the Ford Motor Company to further the development of the patented Ford research instrument and to make it commercially available.

## How the LL OWL Works to Reduce Accidents

As you drive down the highway you are constantly moving the steering wheel back and forth to keep the car properly on the road. These movements are called steering wheel reversals, and a single reversal, which can be a back and forth motion as small as 2°, is illustrated at the right. Drivers can average anywhere from 20 to 50 such motions in one minute on the highway and each driver has his own individual profile of driver behavioral pattern.

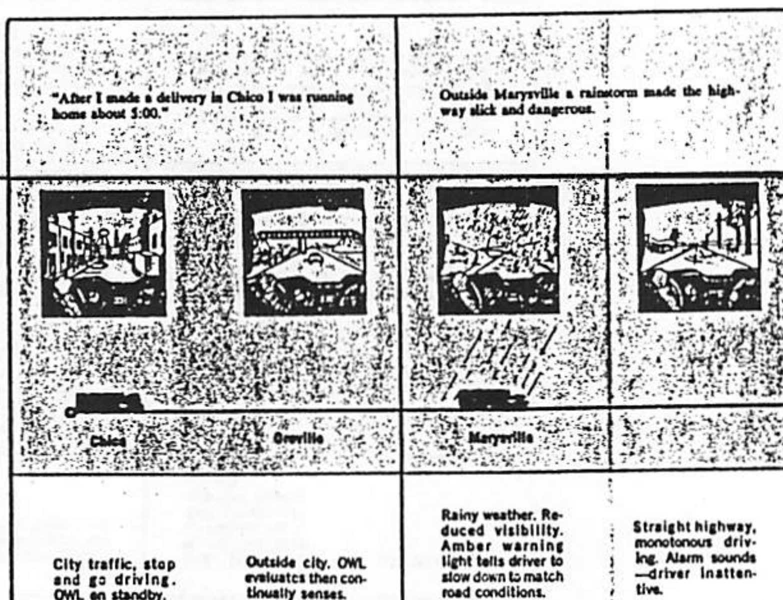
The steering wheel reversal rate is the number of reversals a driver averages in a given period. This is a true profile of the individual driver's highway tracking habits. And this rate remains quite constant, even with noticeable changes in road conditions. For example, three different reversal rates are depicted at the right: high, medium and low. An alert driver in any of the reversal rate categories will unconsciously tend to drive at this same *rate* regardless of road conditions. He will usually slow down or speed up his vehicle to maintain a constant reversal rate which is comfortable for him. Occasionally, however, a driver becomes inattentive, causing him to reverse his steering wheel at a rate slower than his normal.




Conversely, there are times when driving too fast for conditions might raise his reversal rate above normal.

The LL OWL uses this reversal rate principle, profiling the driver at the start of a trip and constantly comparing his ongoing tracking habits against this stored profile.

This is Mr. L. E. "Jim" James, an owner-operator who drives contract for one of the largest moving and storage companies. We put an LL OWL in his cab for testing under actual long haul conditions. Here's what Jim has to say about the LL OWL. "I found the machine very adequate. The thing that I noticed most while driving is that the machine will definitely tell you when you are not paying attention. After the warning comes on, if you check back on your driving pattern, you will definitely find that you have not been paying attention."



## The Iti OWL in Operation

Driver starts vehicle, OWL. is on standby immediately—needs no warmup because of its solid state integrated circuits. It remains on standby until the vehicle speed reaches 35 mph. At that point the Iti OWL counts reversals for about three minutes, computes this into reversal rate and stores this tracking profile in the memory circuit.

The driver's ongoing reversal rate is then continually compared with his normal range stored in the memory circuit, and as long as the reversal rate falls within this range no warnings will be given.

If the reversal rate drifts outside the safety range warning devices will alert the driver so he can take the necessary action before serious trouble develops. There are two warning devices in the Iti OWL:

**An audible alarm for too low a reversal rate, and**
**An amber caution light for too high a reversal rate.**

### Driver Inattentive — Alarm Sounds

If the reversal rate falls below the stored safety range, it is an indication that the driver is inattentive. This can be due to drowsiness, fatigue, medication (certain cold remedies, for example), hypnosis from long stretches of vacant highway or just plain daydreaming. Whatever the cause, when the reversal rate goes below the stored safety range an alarm will sound, waking the driver from his other world into the reality of the situation alert. Amazingly, the Iti OWL spots momentary driving lapses before the driver even realizes he is being inattentive and warns by the alarm well in time for the driver to return to normal, alert driving.

### Driver Goes Too Fast for Road Condition — Amber Caution Light Appears

If the reversal rate goes above the stored safety range it is usually an indication that the driver is going too fast for existing road conditions or is in a general state of nervousness or tension. When this happens an amber caution light on the panel will signal the driver, and the light will go off only after the driver has corrected the cause of the high reversal rate.

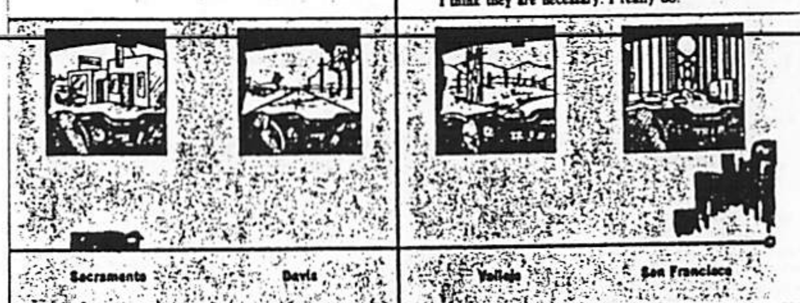
## Iti OWL Reports Only to the Driver

The Iti OWL is not a trip recorder. As a matter of fact it doesn't record at all. Instead, it is an electronic "Road Buddy" designed solely to help the driver be a better—and therefore a safer—driver.

Long stretch of straight highway, monotonous driving. "I knew I was getting tired and so did this machine, because the alarm kept going on and off. So I stopped the truck, got out, kicked the tires, then went into an all night cafe for coffee. Then I was all right for a while."

"After I left Vallejo I could feel that I was tired again. I was close to home and wanted to get home, no matter how tired I was. This machine kept sounding the alarm, so I do know it works."

"I would say that one should be in every car. I think they are necessary. I really do."




After warning, driver stops.

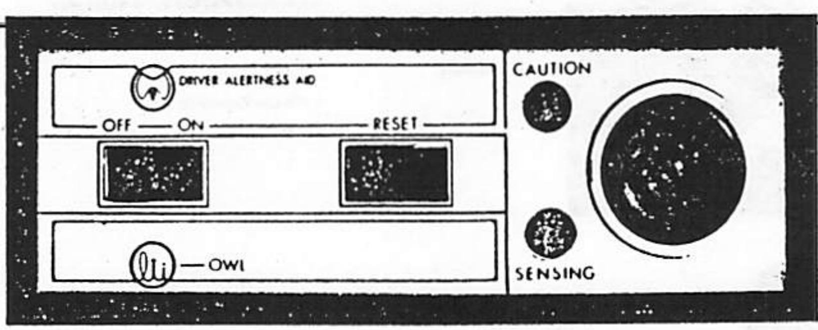
OWL on standby until driver starts again, vehicle reaches 35 mph, the OWL reevaluates then senses.

Driver tiring again. OWL alarm sounds. Helps driver stay alert.

Driver and vehicle reach destination safely, helped by Iti OWL "Electronic Road Buddy."

**Highway accidents can be drastically reduced. Life and property can be dramatically saved with the OWL Driver Alertness Aid. An electronic sensing device that follows steering wheel reversals can alert the driver to physiological changes such as drowsiness, fatigue, hypnosis, preoccupation or tension.**

**A small computer incorporated in the sensor can automatically calibrate to the characteristic driving habits of any operator and warn him when he has drifted too far from his driving norm to constitute a hazard to himself and others on the road.**


**— OWL DRIVER ALERTNESS AID**

# lti-OWL DRIVER ALERTNESS AID

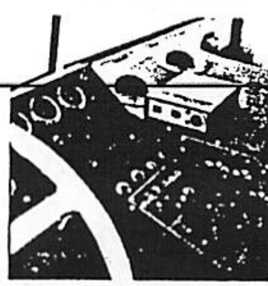
## Driver Need Not Touch the lti OWL

Under normal conditions the driver doesn't touch the lti OWL . It doesn't require any calibration and there aren't any knobs to set or dials to read. You don't even have to turn it on and off; it's wired in series with the ignition. In short, it's completely automatic.

On rare occasions the lti OWL may give out warnings when the driver is neither tense nor inattentive. This is usually caused by the driver being "profiled" under abnormal conditions such as a stretch of highway under construction or the driver being unusually tense at the start of a trip with the tenseness relaxing as he drives. All the driver has to do in such cases is touch a reset button. The lti OWL. will then profile and store a new pattern and continue to work for the driver. At no time does the lti OWL take over the driving — the driver is always in the driver's seat.

### INSTALLATIONS

In-Dash
Circular Model



Rectangular Model
Above Dash

### TECHNICAL SPECIFICATIONS

**Temperature Tolerance**
The lti OWL has been tested from −20° to +140° F.

**Vibration Tolerance**
The lti OWL has been tested over 10 times the force of gravity.

**Electrical Requirements**
12 volts D.C.
Draws less than one amp.

**Dimensions**
Under Dash Rectangular Model
Width—6½ inches
Height—2½ inches
Depth—8½ inches

**In-Dash Circular Model**
2-1/16 inches diameter by 2¾ inches deep.
~~(fits in standard cutout for small gauge)~~



lti life technology inc.
2361 stanwell drive concord, california 94520 telephone (415) 687-4760

Appendix B (Con't)

Safex "Drive Alert"

# BIBLIOGRAPHY


Allen, John; Schroeder, Stephen R.; Ball, Patricia G.
Effects of experience and short-term practice on drivers eye movements and errors in simulated dangerous situations.
Perceptual and Motor Skills, 1978, 47, 767-776.

Allen, R. Wade
Modeling driver steering control behavior.
1982 IEEE International conference on Cybernetics and Society. Paper No. 322, Seattle, Washington, 28-30 October 1982.

Allen, R. Wade; Jex, Henry R.; McRuer, Duane T.; DiMarco, Richard J.
Alcohol effects on driving behavior and performance in a car simulator.
IEEE Transactions on Systems, Man, and Cybernetics, 1975, Vol SMC - 5(5), 498-505.

Allen, R. Wade; McRuer, Duane T.
The effect of adverse visibility on driver steering performance in an automobile simulator.
Society of Automotive Engineers, 1977, Paper No. 770239.

Allen, R. Wade; McRuer, Duane T.
The effect of adverse visibility on driver steering performance.
Society of Automotive Engineers: 1977, Paper no. 770239, Detro

Allen, R. Wade
Stability and performance analysis of automobile driver steering control
Society of Automotive Engineers: 1982 Paper No. 820303, Detroit, MI

Attwood, Dennis A.
The effects of driving experience on objective measures of driving performance.
Proceedings of 23rd Annual Meeting of the Human Factors Society, Boston, MA, October 29 - November 1, 1979.

Atwood, Dennis A.; Scott, Philip L.
The on-line use of performance measures to predict driving fatigue.
Proceedings of the 25th Annual Meeting of the Human Factors Society, Boston, MA, 1981, 726-730.

Attwood, D.A.; Williams, R.D.; Madill, H.P.
The effects of moderate concentrations of alcohol on closed course driving.
J. Studies Alcohol, 1980, 41(7), 623-634

Baron, Sheldon
An Optimal Control Methodology for analyzing the effects of display parameters on performance and workload in manual flight control.
IEEE Trans. Syst., Man, Cybernetics, 1975, Vol. SMS - 5(4), 423-430.

Baxter, J.; Harrison, J.Y.
A Non-Linear Model Describing Driver Behavior on Straight Roads
Human Factors, 1979, 21(1), 87-97.

Beatty, J.; Wagoner, B.L.
Pupilometric signs of brain activity vary with levels of objective processing.
Science, 1978, 199, 1216-1218.

Beideman, Larry R.; Stein, John A.
Aspects of the eyeblink during simulated driving as a function of alcohol.
Human Factors, 1977, 19(1). 73-77.

Bekey, George A.; Burnham, Gerald E.; Sev, Jinbom
Control Theoretic Models of Human Drivers in car following.
Human Factors, 1977, 19(4), 399-413

Belt, B.L.
Driver eye movements as a function of low alcohol concentrations
Columbus, Ohio: Driving Research Laboratory Technical Report. Department of Industrial Engineering, Ohio State University, 1969

Blaauw, Gerard J.
Driving experience and task demands in simulator and instrumented car: A validation study.
Human Factors, 1982, 24(4), 473-486

Blaaw, Gerard J.; Godthel P.J.; Moraal, J.
Driver's lateral control strategy as affected by task demands and driving experience.
SAE Paper No. 770876, Detroit, MI, Society of Automotive Engineers, 1977.

Brewer, N.; Sandow, B.
Alcohol effects on driver performance under conditions of divided attention.
Ergonomics, 1980, 23(3), 185-190

Brown, I.D.
A comparison of two subsidiary tasks used to measure fatigue in car drivers.
Ergonomics, 1965, 8(4), 467-473

Buikhuisen, W.; Jongman, R.W.
Traffic Perception under the influence of alcohol.
Quarterly Journal of the Studies of Alcohol, 1972, 33, 800-806

Burdick, J.A.; Brinton, G.; Goldstein, L.; Laszio, M.
Heart rate variability in sleep and wakefulness.
Cardiology, 1970, 55, 79-83

Cameron, C.
Fatigue and driving - A theoritical analysis
Australian Road Research, 1973, 5(2), 36-44

Ceder, Avishai
Driver's eye movements as related to attention in simulated traffic flow conditions.
Human Factors, 1977, 19(6), 571-581

Dobbins, D.A.; Tiedeman, J.G.; Skordahl, D.M.
Vigilance under highway driving conditions.
Perceptual and Motor Skills, 1963, 16, 38-

Donges, Edmund
A two-level model of driver steering behavior.
Human Factors, 1978, 20(6), 691-708

Duffy, E.
Activation and Behavior, Wiley, New York, 1962

Egelund, Niels
Spectral analysis of heart rate variability as an indicator of driver fatigue.
Ergonomics, 1982, 25(7), 663-673

Erwin, D.W.; Volow, M.R.; Gray, B.
Psychophysiologic correlates of drowsiness.
Society of Automotive Engineers, 1973, Paper No. 730122, Detroit, MI

Faulkner, W.H.; Onston, E.D.
Error rate information in attention allocation models.
Proceedings of the 13th NASA Universtiy conference on Manual Control, Massachusetts Institute of Technology, June 15-17, 1977, 72-78

Garrot, W. Riley; Wilson, Douglas L; Scott, Richard A.
Closed loop automobile maneuvers using preview-predictor models.
Society of Automotive Engineers, 1982, Paper No. 820305, Detroit, MI

Garrot, W. Riley; Wilson, Douglas L.; Scott, Richard A.
Closed loop automobile maneuvers using preview-predictor models.
Society of Automotive Engineers: 1982, Paper No. 820306, Detroit, MI

Gopher, Daniel
Eye-movement patterns in selective listening tasks of focused attention.
Perception and Psychophysics, 1973, 14(2), 259-264

GrandJean, E.
Psychological and Physiological reactions associated with repetitive tasks.
Proceedings: 24rd Annual Meeting of the Human Factors Society, Boston, MA, October 29 - November 1, 1979

Greenshields, B. P.
Driving behavior and related problems.
Highway Research Record, 1963, 25, 14-32

Greenshields, B. P.
Changes in driver performance with time in driving.
Highway Research Record, 1966, 122, 75-88

Greenshields, B. P.; Platt, F. N.
Development of a method of predicting high-accident and high-violation drivers.
Journal of Applied Psychology, 1967, 51, 205-210

Hagen, Roger E.
Sex differences in driving performance.
Human Factors, 1975, 17(2); 165-177

Haight, F. A.
A mathematical model of driver alertness.
Ergonomics, 1972, 15(4), 367-378

Hamilton, P.; Copeman, A.
The effect of alcohol and noise and components of a tracking and monitoring task.
Br. J. Psychology, 1979, 61(2), 149-156

Hecks, T. G.; Wierwille, W. W.
Comparison of five mental workload assessment procedures in a moving-base driving simulator.
Human Factors, 1979, 21(2), 129-143

Heftley, E.; Wickens, C.; Donchin, W.
Intramodalty selective attention and P300 - Reexamination in a visual monitoring task.
Psychophysiology, 1978, 15, 269-270

Helander, Martin
Applicability of drivers' electrodermal response to the deisgn of the traffic environment.
Journal of Applied Psychology, 1978, 63(4), 481-488

Hildebrandt, Gunther; Rohmert, Walter; Rutenfranz, Joseph
12 and 24 H Rhythms in error frequency of locomotive drivers and the influence of tiredness.
International Journal of Chronobiology, 1974, 2, 175-180

Holahan, Charles J.; Culler, Ralph E.; Wilcox, Brian L.
Effects of visual distractions on reaction time in a simulated traffic environment.
Human Factors, 1978, 20(4), 409-413

Howitt, J. S.; Hay, A. E.; Shergold, G. R.; Ferres, H. M.
Workload and fatigue-in-flight EEG changes.
Aviation, Space, and Environmental Medicine, 1978, 49(10), 1197-1202

Hyndman, B.; Gregory, J. R.
Spectral analysis of sinus arrhythmia during mental loading.
Ergonomics, 1975, 18, 225 - 270

Isreal, Jack B.; Wickens, Christopher D.; Chesney, Gregory L.; Donchin, Emanuel
The event-related brain potential as an index of display-monitoring workload.
Human Factors, 1980, 22(22), 211-224

Jaeger, Robert J.; Agarwal, Cyan C.; Gottlieb, Gerald L.
Predictor operator in pursuit and compensatory tracking.
Human Factors, 1980, 22(41), 497-506

Jex, Henry R.; Magdaleno, Raymond E.
Corroborative data on normalization of human operator remnant.
IEEE Transactions on Man-Machine Systems, 1969

Johannsen G.; Govindaraj, T.
Optimal control model predictions of system performance and attention allocation and their experimental validation in a display design study.
IEEE Trans, System, Man, Cybern, 1980, SMC-10(5), 249-261

Kahneman, D.
Attention and effort, 1
Englewood Cliffs, NJ: Prentice Hall, 1973

Kazuyoshi, Yajima; Kenji, Ideda; Oshima, Masamitsu
Fatigue in automobile drivers due to long-time driving.
Society of Automotive Engineers, 1976, Paper No. 760050, Detroit, MI

Konz, Stephan; McDougal, David
The effect of background music on the control activity of an automobile driver.
Human Factors, 1968, 10(3), 233-244

Lacy, B.C.; Lacey, J.I.
Studies of heart rate and other bodily processes in sensor motor behavior.
In P.A. Obrist, A.H. Black, J. Brener, and L.V. DiCava (Eds.) Cardiovascular Psychophysiology: Current issues in response mechanisms, biofeedback and methodology. Chicago, Aldine, 1974

Lane, N. E.; Wherry, R. J., Jr.
The human operator simulator: Estimation of workload reserve using a simulated secondary task.
Proceedings of the AGARD conference on methods to assess workload. AGARD-CPP-216, Aril 1977, A11-1

Laurell, H.; Lisper, H. D.
Changes in subsidiary reaction time and heart rate during car driving, passenger travel, and statutory conditions.
Ergonomics, 1976, 19(2), 149-156

Lemke, M.
Correlation between EEG and drivers' actions during prolonged driving under monotonous conditions.
Accident Analysis and Prevention, 1982, 14(1), 7-17

Leonard, James J. Jr.; Wierwille, Walter W.
Human performance validation of simulators; theory and experimental verification.
Proceedings of the 19th annual meeting of the Human Factors Society, 1975, 446-456

Lindquist, A.; Keskinen, E.; Antila, K.; Halkola, L.; Peltonen, T.; Valimaki, L.
Heart rate variability, cardiac mechanics, and subjectively evaluated stress during simualtor flight.
Aviation, Space, and Environmental Medicine, 1983, 54, 685

Linnoila, M.
Effects of drugs and alcohol on psychomotor skills related to driving.
Annals of Clinical Research, 1974, 6, 7-18

Linnoila, M.; Mattila, M. J.
Effects of isoniazid on psychomotor skills related to driving.
The Journal of Clinical Pharmacology, 1973, 343-350

Lisper, H. O.; Dureman, I.; Ericson, S.; Karlson, N. G.
Effects of sleep deprivation and prolonged driving on a subsidiary reaction time.
Accident Analysis and Prevention 1971, 2, 335-341

MacDonald, Wendy A.; Hoffman, Errol R.
Review of relationship between steering wheel reversal rate and driving task demand.
Human Factors, 1980, 22(6), 733-739

MacDonald, Wendy A.; Hoffman, Errol R.
A secondary task measure of driving demands: test track evaluation.
Australian Road Research Board, Research Report, AAR No. 70, 1977

Mackie, Robert R.; Miller, James C.
Effects of hours of service, regularity of schedule, and cargo loading on track and bus driver fatigue.
Final Report No. DOT HS-803 799, 1978

Malmo, R.B.
Activation: A neuropsychological dimension.
Psychological Review, 1959, 66, 367-386.

Mast, T. M.; Jones, H. W.; Heimstra, N. W.
Effects of fatigue on performance in a driving device.
Highway Research Record, 1966, 122, 93

Moskowitz, Herbert; Ziedman, Kenneth; Sherman, Santano
Visual search behavior while viewing driving scenes under the influence of alcohol and marihuana.
Human Factors, 1976, 18(5), 417-432

Mortimer, R. G.; Jorgeson, C. M.
Eye fixations of drivers as affected by highway and traffic characteristics and moderate doses of alcohol.
Proceedings of the 16th Annual Meeting of the Human Factors Society, October 17-79, 1972, Los Angeles, 86-92

Mortimer, R. G.; Sturgis, S. P.
Effects of low and moderate levels of alcohol on steering performance.
In S. Israelstam and S. Lambert (Eds.) Proceedings of Sixth International Conference on Alcohol, Drugs, and Traffic Safety, 1975, 329-345. Toronto: Addiction Research Foundation of Ontario

Mortimer, R. G.; Sturgis, S. P.
Some effects of alcohol on car driving on two-lane and limited-access highways.
Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, MA, October 29 - November 1, 1979

Moskowitz, Herbert; Ziedman, Kenneth; Sherman, Santano; McDonald L. Bruce; Ellis, Newton, C.
Driver workload for various turn radii and speeds.
In Transporation Research Board, No. 53, 1975

Mourant, R.R.; Rockwell, T.H.
Drivers' Eye Movements and visual workload.
Human Factors, 1970, 12(1), 81-87

Mourant, R.R.; Rockwell, T.H.
Strategies of visual search by novice and experienced drivers.
Human Factors, 1972, 14(4), 325-335

McLean, J. R.; Hoffman, E. R.
Analysis of drivers' control movements
Human Factors, 1971, 13(5), 407-418

McLean, J. R.; Hoffman, E. R.
The effects of lane width on driver steering control and performance.
Proceedings of the Australian Road Research Board Sixth Conference, 1972, 6(3), 418-440

McLean, J. R.; Hoffman, E. R.
The effects of restricted preview on driver steering control and performance.
Human Factors, 1973, 15( ), 421-440

McLean, J. R.; Hoffman, E. R.
Steering reversals as a measure of driver performance and steering task difficulty.
Human Factors, 1975, 17(3), 248-256

McLane, R. C.; Wierwille, W. W.
The influence of motion and audio cues on driver performance in an automobile simulator.
Human Factos 1975, 17( ), 488-501

McRuer, Duane T.; Allen R. Wade; Weir, David H.; Klein, Richard H.
New results on driver steering control models.
Human Factors, 1977, 19(4), 381-397

McRuer, D. T.; Klein, R. H.
Comparison of human driver dynamics in an automobile on the road with those in simulators having complex and simple visual displays.
Paper on 53rd Annual Meeting of the Transportation Research Board, Washington, DC 1976

Noble, Merril; Sanders, Andries F.
Searching for Traffic signals while engaged in compensatory tracking.
Human Factors, 1980, 22(1), 89-102

Ogden, George, D.; Levine, Jerrold M.; Eisner, Ellen J.
Measurement of workload by secondary tasks.
Human Factors, 1979, 21(5), 529-548

O'Hanlon, James F.; Horvath, Steven M.
Interrelationships among performance, circulating concentrations of adrenaline, glucose, and the free fatty acids in men performing a monitoring task.
Psychophysiology, 1973, 10(3), 251-259

Opmeer, C. H. J. M.
The information content of successive RR - interval times in the ECG. Preliminary results using factor analysis and frequency analysis.
Ergonomics, 1973, 16, 105-112

Phatak, A. V.
Formulation and validation of optimal control theroetic models of the human factors operator.
Man-Machine Systems Review, 1976, 2, 11-12

Platt, Fletcher, N.
Heart rate measurements of drivers with the highway systems research car.
Industrial Medicine, 1969, 38(10), 59-68

Platt, F. N.
A new method of evaluation the effects of fatigue on driver performance.
Human Factors, 1964, 6, 351-358

Putz, Vernon R.
The effects of carbon monoxide on dual task performance.
Human Factors, 1979, 21(1), 13-24

Reddy, R.N.; Ellis, J.R.
Contribution to the simulation of driver-vehicle-road system.
Society of Automotive Engineers: 1981, Paper No. 810513, Detroit, MI

Regina, Edmund G.; Smith, Gene M.; Kieper, Charles G.; McLelvey, Robert M.
Effects of caffeine on alertness in simulated automobile driving.
Journal of Applied Psychology, 1974, 59(4), 483-489

Reid, L. P.; Solowka, E. N.; Billing, A. M.
A systematic study of driver steering behavior.
Ergonomics, 1981, 24(6), 447-462

Reid, L. P.; Graf, W. V.; Billing, A. M.
The fitting of linear models to driver response records.
Society of Automotive Engineers, 1982, Paper No. 820304, Detroit, MI

Reid, L. P.
A survey of recent driver steering behavior models suited to accident studies.
Accident Analysis and Prevention, 1983, 15(1), 23-40

Riemersma, Johan B. J.; Biesta Paul W.; Widervanck, Cees
Fatigue and stress due to prolonged driving and changing task demands.
Society of Automotie Engineers, 1977, Paper No. 770134, Detroit, MI

Rockwell, T.H.; Bhise, V.D.; Nemeth, Z.A.
Development of a computer based tool for evaluating visual field requirements of vehicles in merging and intersection situations.
Project RF3306 Final Report, Ohio State University, Department of Industrial and Systems Engineering, Columbus, Ohio, 1973

Rouse, William B.; Gopher, Daniel
Estimation and Control theory; Application to modeling behavior.
Human Factors, 1977, 19(4), 315-330

Safford, R. S.; Rockwell, T. H.
Performance decrement in 24-hour driving.
Highway Research Record, 1967, 163, 68-79

Safren, M.; Cohen, S.; Schlesinger, L.
The driveometer as a measure of driving skill.
Journal of Safety Research, 1970, 2, 30-35

Schmolling, P.; Lapidus, L.B.
Arousal and task complexity in schizophrenic performance deficit: A theoretical discussion.
Psychological Reports, 1972, 30, 315-326

Schneider, W.; Shiffrin, R. M.
Controlled and automatic human information processing: I. Detection, search, and atttention.
Psychologicial Review, 1977, 84, 1-66

Schroeder, David J,; Gilson, Richard D.; Guedry, Frederick E.; Collins, William E.
Effects of alcohol on nystagmus and tracking performance during laboratory angular accelerations about the y and z axes.
Aerospace Medicine, 1973, 44(5), 477-483

Sekiguchi, Chiharu; Handa, Yasunobu; Gotoh, Masara; Kurihara, Yoshinori; Nagasawa, Yukoh; Kuroday, Isao
Frequency analysis of heart rate variability under flight conditions.
Aviation, Space, and Environmental Medicine, 1979, 50, 625-634

Sem-Jacobsen, C. W.
Brain/computer communication to reduce human error: a perspective.
Aviation, Space, and Environmental Medicine, 1981, 52(1), 33-37

Shinar, David; McDowell, Edward D.; Rackoff, Nick J.; Rockwell, Thomas H.
Field dependence and driver visual search behavior.
Human Factors, 1978, 20(5), 553-560

Shinar, David; McDowell, Edward D.; Rockwell, Thomas H.
Eye movements in curve negotiations.
Human Factors, 1977, 19(1), 63-71

Shirley, Richard S.
Application of a modified fast fourier transform to calculate human operator describing functions.
IEEE Transactions on Man-Machine Systems, 1969

Smiley, Alison; Reid, Lloyd; Fraser, Morris
Changes in driver steering control with learning.
Human Factors 1980 22(4), 401-415

Snook, S. H.; Dolliver, J. J.
Driver Fatigue: A study of two types of countermeasures.
Proceedings of the 6th Congress, International Ergonomics Association, College Park, Maryland, 1979, 304-311

St. John, A. P.
Freeway driving simulation shows lapses of attention are critical.
SAE Journal, 1969, 77(8), 36-39

Stroh, C.M.
Vigilance: The problem of sustained attention.
Oxford: Pergamon Press, 1971

Summala, Keikki; Leino, Matti; Vierimaa, Jukka
Drivers' steering behavior when meeting another car: the case of perceptual tropism revisited.
Human Factors, 1981, 23(2), 185-189

Tole, J. R.; Stephens, A. T.; Harris, R. L., Sr.; Ephratch, A. R.
Visual scanning behavior and mental workload in aircraft pilots.
Aviation, Space, and Environmental Medicine, 1982, 53(1), 54-61

Triggs, T. J.; Caple, D. C.
Visual sampling by drivers in night vs. day conditions.
In T. J. Triggs (Ed) Human Factors and Contemporary Society: Proceedings of the 15th annual conference of the Ergonomics Society of Australia and New Zealand, Melbourne, 1979

Tsach, Uri; Sheridan, Thomas B.; Buharali, Ahmet
Failure detection and location in process control-integrating a new model based technique with other methods.
1983 American Control Conference, June 22-24, San Francisco, CA

Watanabe, A.; Kogi, K.; Onishi, N.; Shindo, H.; Sakai, K.
Fatigue of bullet-train drivers operating on multi-tunnelled sections.
Ergonimics, 1982, 24(6), 534

Watson, B. L.
The effect of secondary tasks on pilots describing functions in a compensatory tracking task.
Toronto, Canada; University of Toronto, Insititute for Aerospace Studies, UTUAS Technical Note No. 178, June 1982

Weir, D. H.; McRuer D. T.
Dynamics of driver vehicle steering control.
Automatica, 1970, 6, 87-98

Weir, David H.; McRuer, Duane T.
Measurement and interpretation of driver vehicle system dynamic response.
Human Factors, 1973, 15(4), 367-378

Whitaker, Leslie A.
Dual-task interference as a function of cognitive processing load.
Acta Psychologica, 1979, 43, 71-84

Wickens, C. D.
The structure of attentional resources.
In R. Nickerson (Ed) Attention and Performance VIII. Englewood Cliffs, NJ, Erlbaum, 1980

Wickens, C. D.; Gopher, D.
Control theory measures of tracking as indices of attention allocation strategies.
Human Factors, 1977, 19, 349-365

Wickens, C. D.; Isreal, J.; Donchin, E.
The event-related cortical potential as an index of task workload.
Proceedings of the 21st Annual Meeting of the Human Factors Society, October 1977, San Francisco, CA

Wickens, Christopher D.; Kramer, Arthur F.; Heffley, Earle F.; Donahin, Emanuel
The event related brain potential as an index of attention allocation in complex displays.
Proceedings of the 24th Annual Meeting of the Human Factors Society, 1980, Los Angeles, CA

Wierwille, Walter W.
Physiological Measures of Aircrew Mental Workload.
Human Factors, 1979, 21(5), 575-593

Wierwille, Walter W.; Muto, William H.
Significant changes in driver/vehicle response measures for extended duration simulation driving tasks.
Proceedings of the First European Annual Conference on Human Decision Making and Manual Control, Delft University of Technology, Delft, Netherlands, May 25-26, 1981

Wildervanck, G. Mulder; Michon, J. A.
Mapping mental load in car driving.
Ergonomics, 1978, 21(3), 225-229

Williams, Leonard J.
Cognitive load and the functional field of view.
Human Factors, 1982, 24(6), 683-692

Williges, Robert C.; Wierwille, Walter W.
Behavioral measures of aircrew mental workload.
Human Factors, 1979, 21(5), 549-574

Willsky, Alan S.
A survey of design methods for failure detection in dynamic systems.
Automatica, 1976, 12, 601-611

Wilson, Fay; Greensmith, John
Multi-variate Analysis of the Relationship between driveometer variables and drivers' accident, sex, and exposure status.
Human Factors, 1983, 25(3), 303-312

Wingrove, Rodney C.; Edwards, Frederick G.; Lopez, Armando E.
Some examples of pilot/vehicle dynamics indentified from flight test records.
IEEE Transactions on Man-Machine Systems, 1969

Zaidel, David M.; Paarlberg, William T.; Shinar, David
Driver performance and individual differences in attention and information processing.
Final Report No. DOT-HS-8-01819, 1978

Ziedman, K.; Moskowitz, H.; Nieman, R. A.
The effects of alcohol on the drivers' visual information processing.
Final Report No. DOT-GS-805-748, September 1980

Ziedman, Kenneth; Smiley, Alison; Moskowitz, Herbert
Effect of drugs on driving: Driving simulator tets of diazephan and secobarbitol.
Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, MA, October 29 - November 1, 1979

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