



U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

Research Note

November, 1994

Crashes and Fatalities Related to Driver Drowsiness/Fatigue

Ronald R. Knipling
NHTSA

Jing-Shiam Wang
Information Management Consultants, Inc.

This report summarizes recent national statistics on the incidence and characteristics of crashes involving driver fatigue, drowsiness, or “asleep-at-the-wheel. For the purposes of this report, these terms are considered synonymous. Principal data sources are the NHTSA General Estimates System (GES) and the Fatal Accident Reporting System (FARS), although these data files are acknowledged to have limitations for quantifying this type of crash causal factor. Most data provided are for the five-year period 1989-93. Findings from other studies of the incidence of drowsiness/fatigue in crashes are reviewed. Finally, overviews are provided of NHTSA programs underway to help provide better data to assess this traffic safety problem and more importantly, to develop effective countermeasures.

National Crash Problem Size Statistics

NHTSA General Estimates System (GES) statistics for 1989-93 indicate that there were an estimated 56,000 crashes annually in which driver drowsiness/fatigue was cited on the Police Accident Report (PAR). This was about one percent of the average total of 6.3 million police-reported crashes occurring annually during this time period. Other studies of large crash data files (reviewed later in this report; see Page 3) have generally yielded estimates in the 1-4 percent range. Reasons for regarding the GES estimate of one percent as somewhat conservative include the following:

- Reporting practices for the citing of driver drowsiness/fatigue on the PAR vary from state to state. Most states include drowsiness/fatigue as a **check-off** box on the PAR, but others do not. In

the latter case, the factor could still be indicated in the officer's narrative description, but there is no assurance of this.

- Regardless of the state's reporting format, drowsiness may be underreported due to a lack of firm evidence upon which to base a police finding. Officers may be unaware of the role of drowsiness in the crash or may regard available evidence as circumstantial and not verifiable.
- Crash-involved drivers themselves may not be aware of the role that drowsiness played in their crashes and thus may not report it to police when interviewed. On the other hand, some drivers may consider drowsiness to be a more socially-acceptable explanation for their being involved in a crash than other more censurable errors such as alcohol use, speeding, or inattention.
- A significant number of crashes involve a “drift out of lane” vehicle path but are not cited as drowsiness-related on PARS. Some of these crashes may in fact be drowsiness-related. This issue is addressed later in this report (see Page 5).

Regardless of the exact percentage, it is notable that GES and most other crash data files include **police-reported** crashes only. Overall, fewer than one-half of all crashes are police-reported (Miller, 1991). Little is known about the characteristics of non-police-reported crashes, including the proportion that are drowsy-driver-related. However, since most drowsy driver crashes are single-vehicle crashes, it is likely that a significant percentage go unreported. In single-vehicle crashes without serious injury or damage,



drivers would have little incentive (and some disincentive) to report the incident to police.

Based on GES data, an average of 40,000 non-fatal injuries (i.e., severity levels A, B, and C in the “KABCO” severity scale used by most states) annually were associated with 1989-93 police-reported driver drowsiness crashes.

Data from the 1989-93 Fatal Accident Reporting System (EARS) indicate that drowsiness/fatigue was cited as a factor in an annual average of 1,357 fatal crashes resulting in 1,544 fatalities. This represents approximately 3.6 percent of all fatal crashes and also 3.6 percent of fatalities during those five years. Many of the above caveats regarding drowsy driver crashes in general apply to fatal crashes, with the added problem that many (39 percent) of these fatal crashes involve only one vehicle and only one person – the fatally injured driver.

Table 1 presents annual crashes, injuries, fatal crashes, and fatalities associated with driver drowsiness for the five years from 1989 to 1993. Accompanying each statistic is its percentage of the national total; e.g., percent of all motor vehicle crashes, injuries, fatal crashes, or fatalities. Although some apparent trends are seen, five years is regarded as an insufficient time period to discern long-term trends reliably.

Table 1. **U.S. Motor Vehicle Crashes, Injuries, Fatal Crashes, and Fatalities Associated with Driver Drowsiness/Fatigue.**

Year	Crashes (#/% of total)	Non-Fatal Injuries	Fatal Crashes	Fatalities
1989	72,000/1.1%	52,000/1.7%	1361/3.3%	1,546/3.4%
1990	57,000/0.88%	40,000/1.3%	1423/3.6%	1,596/3.6%
1991	59,000/0.96%	45,000/1.5%	1377/3.7%	1,579/3.8%
1992	50,000/0.84%	33,000/1.1%	1261/3.6%	1,440/3.7%
1993	43,000/0.71%	32,000/1.1%	1,362/3.8%	1,547/3.9%
Total	280,000/0.90%	202,000/1.4%	6,784/3.6%	7,708/3.6%
Average	56,000/0.90%	40,000/1.4%	1,357/3.6%	1,542/3.6%

Sources: 1989-93 GES and FARs. All GES data are rounded to the nearest 1,000 with totals and averages calculated before rounding. Percentages are rounded to 2 significant places.

In addition to drowsiness/fatigue crashes are crashes related to “illness/blackout” as an acute medical condition. During 1989-93 there was an annual average of 9,000 crashes (GES) and 271 fatal crashes resulting in 285 fatalities (EARS) where this factor was cited. Although many “illness/blackout” crashes involve a loss of driver consciousness and crash scenarios similar to those seen in drowsiness/fatigue crashes, they are not addressed further in this report.

Drowsiness in Passenger Vehicle and Combination-Unit Truck Crashes

Two vehicle types are of greatest interest for crash prevention efforts: passenger vehicles (i.e., cars and light trucks) and combination-unit trucks (i.e., tractor-semitrailers, including bobtails). Based on 1989-93 GES data, drivers of passenger vehicles represented 95.9 percent of drowsy driver crash involvements, while those of combination-unit trucks (tractor-trailers) represented 3.3 percent. In terms of the relation of this causal factor to all crash involvements, the problem was relatively greater for trucks; drowsy drivers were cited for 0.82 percent of truck crash involvements during the years 1989-93 versus only 0.52 percent of passenger vehicle crash involvements.

Combination-unit trucks actually had a lower rate per vehicle mile traveled (VMT) of police-reported involvement in these crashes than did passenger vehicles (2.0 versus 2.8 per 100M VMT, based on 1989-92 only), but these trucks have very high exposure levels – an average of about 60,000 miles per year compared to about 11,000 for a passenger vehicle. In addition, they have somewhat longer average operational lives (nearly 15 years) than do passenger vehicles (about 13 years) (Miaou, 1990). Based on 1989-92 target crash involvements, vehicle registrations for these years, and average vehicle operational life, it is estimated that the expected number of target involvements per vehicle life cycle is approximately 4.5 times greater for combination-unit trucks as for passenger vehicles. This statistic is relevant to the issue of perspective benefits from vehicle-based countermeasures. Of course, combination-unit trucks are at greater risk of crash involvement for many different crash types. For *all* types of crash involvements, the expected number of involvements per vehicle life cycle is 2.6 times greater for trucks as for passenger vehicles based on the same four years of data.

In addition to their higher incidence, combination-unit truck drowsy driver crashes are generally more severe in their injury and property damage consequences. For example, GES data indicate an average of 1,800 combination-unit truck and 54,000 passenger vehicle drowsy driver crashes for the period 1989-93. FARS data indicate an annual average of 84 truck-related and 1,429 passenger vehicle-related fatalities associated with these crashes. The fatality-to-crash ratio derived from these statistics is 1.7 times greater for combination-unit trucks than for passenger vehicles.

Figure 1 presents a comparison of passenger vehicles to combination-unit trucks for four different measures of drowsy driver crash problem size: absolute number of crashes, crash involvement rate (per VMT), expected number of involvements over vehicle life, and average crash severity (fatalities per crash). Figure 1 and the statistics cited above show that the overall national drowsy driver crash problem in terms of absolute numbers of crashes (and related injuries and fatalities) is primarily a passenger vehicle problem, and that trucks have a relatively low rate of involvement per vehicle mile traveled. Nevertheless, when viewed from *an individual vehicle* perspective, the drowsy driver crash risk (both crash likelihood and probability of a fatality) *is* considerably greater for combination-unit trucks.

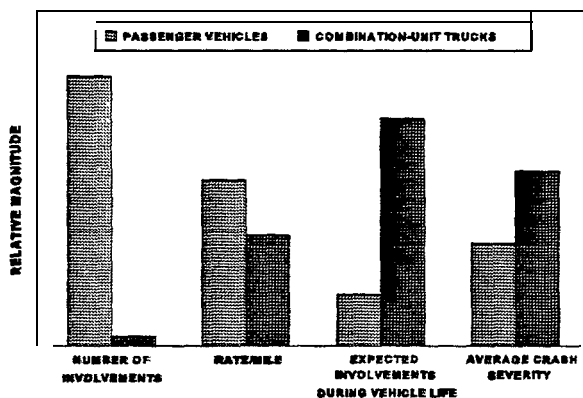


Figure 1. Comparison of Passenger Vehicle to Combination-Unit Truck Crash Problem Size Along Four Parameters.

A further understanding of combination-unit truck drowsy driver crashes arises from statistics showing that much of the human “harm” resulting from these crashes occurs to individuals outside the truck, such as

occupants of other vehicles or pedestrians. In 1989-93, 37 percent of fatalities and 20 percent of non-fatal injuries (A+ B + C in the KABCO scale) associated with truck driver drowsiness crashes occurred to individuals outside the truck. For example, a truck driven by a drowsy driver might rear-end a stationary vehicle with occupants. Comparable percentages of fatalities and injuries occurring outside the subject vehicle (i.e., the vehicle driven by the drowsy driver) for passenger vehicle drowsy driver crashes were 12 percent of fatalities and 13 percent of injuries. Of course, combination-unit truck crashes *in general* result predominantly in fatalities and injuries to individuals outside the truck. For all 1989-93 combination-unit truck crashes, 87 percent of associated fatalities and 75 percent of non-fatal injuries occurred to non-truck occupants.

Other Studies of Crash Problem Size

Perhaps the most in-depth and elaborate study of crash causes ever performed in the U.S. was the Indiana Tri-Level Study (Treat et al, 1979). This study employed multidisciplinary teams who responded to the initial distress call to police following the crash and performed a multidisciplinary investigation including scene inspection, vehicle inspection, and in-depth interviews with drivers and witnesses. The Tri-Level study reported that 2.1 percent of its 420 in-depth cases involved “critical driver non-performance” (i.e., loss of consciousness) as a certain or probable factor in the crash. A much larger percentage of crashes—56 percent—involved “recognition errors” as a certain or probable factor. This category included situations where a *conscious* driver did not properly perceive, comprehend, and/or react to a situation requiring some control response such as braking or steering. The role of fatigue in such recognition failures and other mental errors resulting in crashes is currently unknown.

Najm et al (1994) report the results of a review of nearly 700 Crashworthiness Data System (CDS) and GES case files; 3.7 percent of these cases were identified as being caused primarily by driver drowsiness. In this study, experienced crash reconstructionists reviewed accident research case files and made a subjective determination of probable crash cause based on available information. The crash sample was large and involved a variety of specific crash types, but was not wholly representative of these data files or of the national crash picture. Recognition

errors were cited as the primary cause of 45 percent of the cases in the Najm et al sample.

An individual case review of 1,000 Michigan PARs by General Motors scientists (Deering, 1994) indicated that one percent of sample crashes had the principal causal factor of “dozing.” A total of 17 percent of the crashes were attributed to two awake inattention categories: “daydreaming” and distraction. The recognition error of improper lookout (“looked but didn’t see”) in right-of-way situations accounted for another 18 percent.

Other studies of the incidence of drowsiness/fatigue-related crashes have generally focused on defined, limited samples of crashes, such as single vehicle roadway departure (SVRD) crashes or certain classes of combination-unit truck crashes. Hendricks et al (1994) reviewed the CDS case files of 201 1993 SVRD passenger vehicle crashes to determine causal factors. They identified “fell asleep” as the principal causal factor in 6.9 percent of sample crashes and driver inattention as the principal causal factor of an additional 12.7 percent. SVRD crashes represented 32.6 percent of all crashes in the 1993 CDS. Based on an assumption that 80 percent of drowsy driver crashes are SVRD crashes (see the discussion of statistical characteristics later in this report), the 6.9 percent “fell asleep” estimate from the Hendricks *et al* SVRD crash sample can be extrapolated to an estimated 2.8 percent “fell asleep” for all crashes (i.e., $0.069 \times 32.6/0.80$).

Harris and Mackie (1972) reported research showing that 39 percent of combination-unit truck crashes were attributable to driver drowsiness/fatigue or inattention. The American Automobile Association Foundation for Traffic Safety (1985) examined a sample of heavy truck crashes in seven Western states in which the combination-unit truck had been towed from the scene. The principal criterion for the determination of the presence of driver fatigue was continuous on-duty time; i.e., fatigue was designated to be the primary cause if the driver had been on duty for more than 15 consecutive hours (a violation of Federal hours-of-service regulations). Fatigue was judged to be a primary cause of 90 of 221 crashes (41 percent), and a contributory cause in an additional 40 crashes (18 percent).

A 1990 study by the National Transportation Safety Board (NTSB) identified the principal causal

factors of 182 fatal-to-the-driver heavy truck crashes in eight states. The presence of fatigue was assessed based on a combination of investigative information about the crash scenario (e.g., drift off road), time-of-day, and time-on-duty. Fatigue was judged to be a principal causal factor in 57 (31 percent) of the 182 crashes. The Safety Board cautioned against over-generalizing the findings of this study. Indeed, only about 13 percent of fatal combination-unit truck crashes and 0.1 percent of all combination-unit truck crashes are fatal to the truck driver (based on 1993 FARS and GES data). Moreover, heavy truck crash statistics cannot ordinarily be generalized to the passenger vehicle crash population due to the many physical and operational differences between these vehicle categories.

Driver surveys have indicated that many drivers have experienced dangerous episodes of fatigue while driving. For example, Tilley (1973) conducted a survey of 1,500 drivers and found that 69 percent reported that they had experienced drowsiness while driving. Seven percent reported actually having been involved in such crashes, and another seven percent reported having been involved in near-crashes. The driver survey methodology provides insights on the motor vehicle safety experiences of individual drivers, but it gives no comparative perspective to other crash causes since it does not capture the universe of lifetime crashes and other safety-relevant incidents experienced by subjects. In addition, it is usually not known whether the crashes reported by respondents were police-reported or not, further complicating comparisons to crash data files.

A recent crash problem size analysis in New South Wales, Australia (Fell, 1994) classified crashes as drowsiness-related if either of two criteria were met: 1) the driver was determined by police to be drowsy/fatigued (i.e., drowsiness cited on the PAR), or 2) the pre-crash maneuver of the vehicle “suggest[ed] loss of concentration by the controller [driver] due to fatigue.” Applicable maneuvers were described as lane departures not related to other known contraindicating maneuvers (e.g., passing, evading another crash threat) or causal factors (e.g., excessive speed). Based on these criteria, fatigue was implicated in 6 percent of crashes and 15 percent of fatal crashes occurring in New South Wales in 1992. A later section of this report examines the possibility of identifying U.S. drowsiness-related crashes based on pre-crash vehicle trajectory and other known

information on crash causes apart from a police determination of drowsiness as indicated on the PAR (see below).

This brief review of other studies of the problem size of drowsiness/fatigue-related crashes illustrates the difficulty of drawing firm quantitative conclusions. The studies cited employ different criteria for identifying drowsiness as a cause and often are based on narrowly-defined samples of crashes. These samples may represent important crash populations (e.g., heavy truck crashes), but ordinarily they are not representative of the **universe** of crashes. Survey data regarding the cumulative lifetime experiences of drivers are difficult to relate meaningfully to data about crash samples because such surveys generally cover an vaguely-quantified period of time (all years driving) and employ uncertain criteria for target crashes. They are also subject to the vagaries of human memory, candor, and self-understanding.

Statistical Characteristics of Drowsiness-Cited Crashes

Even if national problem size statistics on drowsiness-cited crashes are not definitive, these statistics can still be used to profile crash characteristics. GES statistics from 1989-93 indicate that drowsy driver crashes peak in the early a.m. hours with a second smaller peak in the afternoon. Fifty-five (55) percent occurred between midnight and 7:59am, and another 18 percent occurred between 1:00 and 4:59pm. These data, though not corrected for exposure, are consistent with expected fatigue-related crash frequencies based on human circadian rhythms (Office of Technology Assessment, 1991).

Most drowsiness/fatigue-related crashes occurred in non-urban areas, generally on roadways with 55-65 mph speed limits. Eighty (80) percent were single-vehicle crashes or collisions with parked vehicles. An additional 6.6 percent were subject vehicle-striking mar-end crashes, and 3.0 percent involved a leftward drift of the subject vehicle resulting in a head-on crash or opposite direction sideswipe.

Most drowsy driver crashes occurred on a straight section of roadway (Of knowns: 81 percent straight, 19 percent curved) with the pre-crash maneuver of "going straight" or "negotiating a curve" (84 percent) as opposed to starting, slowing, stopping, turning, passing, making an evasive maneuver, etc. In 76

percent of crashes the driver was the only occupant of the subject vehicle, and typically the driver made no known corrective action (i.e., braking or steering) to avoid the collision. Alcohol was reported by police to be involved in 15 percent of 1989-93 drowsy driver crashes, although it is recognized that police-reported statistics on alcohol involvement capture primarily observable impairment and not necessarily all alcohol use contributing to driver drowsiness.

Involvement in drowsiness-related crashes is strongly related to both driver sex and driver age. For the 1989-93 period, 76 percent of subject drivers were male. In 1990 (the most recent year for which driver VMT data are available by sex and age), male drivers accounted for 77 percent of the drowsy driver crashes, while representing only 65 percent of VMT and 51 percent of driver registrations. Thus, compared to female drivers, male drivers had a drowsiness crash involvement rate (per VMT) that was 1.8 times greater and an involvement likelihood (i.e., involvements per registered driver) that was 3.1 times greater than that of females.

Strong age-related trends are also evident. For 1989-93, 59 percent of subject drivers were under 30. In 1990, drivers under 30 accounted for 62 percent of subject drivers, while representing only 28 percent of both VMT and driver registrations. Both their drowsiness crash involvement rate (per VMT) and likelihood (per registered driver) were more than four times those of drivers 30 or over.

This statistical profile of U.S. police-cited drowsiness-related crashes is remarkably similar to that reported by Fell (1994) for the same category of crashes occurring in New South Wales, Australia.

"Drift-Out-Of-Lane" (DOOL) Crashes: Drowsiness or Other Factors?

One statistical indication that the number of drowsy driver crashes might be understated by current national statistics is the large number of crashes characterized by a "drift-out-of-lane" (DOOL) scenario, but **not** cited as drowsiness-related on the PAR. GES data indicate that in the years 1989-93 there were an annual average of 965,000 single vehicle or "left side lane drift" crashes where there was no known "active" pre-crash maneuver (e.g., stopping, starting, turning, changing lanes, merging, passing, avoiding other crash threat). Of these DOOL crashes,

an average of 76,000 met several additional criteria: the driver was the only occupant of subject vehicle, no alcohol/drugs cited, speed limit between 45-65mph, no violation charged which would imply alert driving (e.g., reckless driving), dry surface, clear weather, no vehicle defects, and no known avoidance maneuver (e.g., braking or steering) before impact. For the purposes of this report, these crashes are termed “pure” DOOL crashes.

The 56,000 annual crashes for which drowsiness was cited fell into three subcategories in relation to the DOOL scenario: 9,000 were “pure” DOOL scenarios, 31,000 were “other” DOOL scenarios, and 16,000 were non-DOOL scenarios. Examples of non-DOOL crashes are rear-end crashes and single vehicle roadway departure crashes involving an active pre-crash maneuver such as turning or an evasive maneuver to avoid another crash threat.

Figure 2 is a Venn diagram illustrating these overlapping crash categories (each represented by a circle) for the 1989-1993 period. The figure illustrates that the “drowsiness-cited” category (56,000 total) is much smaller than the overall DOOL category (965,000 total) and smaller even than the “pure” DOOL category (76,000 total).

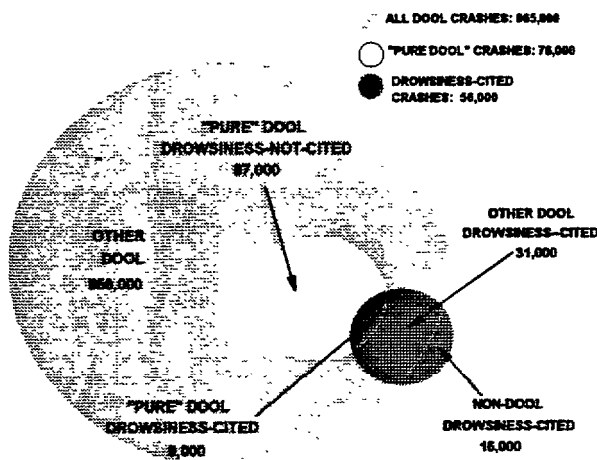


Figure 2. Drowsiness-Cited and Drift-out -of-Lane Crashes (1989-1993 Annual Average)

Drowsiness might seem to be an obvious causal explanation for “pure” DOOL crashes, even when it is not cited on the PAR and captured by GES data

variables. One test of this supposition is to examine the diurnal distribution of these crashes, since daily periods of drowsiness and associated accidents are predictable based on circadian cycles. If the two crash subgroups (“pure” DOOL drowsiness-cited versus not-cited) were equally related to drowsiness, they would likely have similar time-of-day frequency distributions. A comparison of the time-of-day profile of the two “pure” DOOL subgroups reveals distinctive differences, however (see Figure 3). The “drowsiness-cited” crashes peaked sharply in the early morning and had a smaller peak in the afternoon. The “drowsiness not cited” crashes were more evenly distributed throughout the 24-hour day, with a small peak in the late afternoon. It seems reasonable to conclude from this lack of similarity that other factors besides drowsiness are operative in many of these so-called “pure” DOOL, drowsiness-not-cited crashes. Some percentage of these crashes could still be related to drowsiness, however. A preliminary review of individual GES cases in this category corroborates this view. Future research might focus on obtaining more empirical data on the likely causal factors involved in these crashes. A better understanding of their causes would further understanding both of drowsiness/fatigue and of other factors (e.g., driver inattention) related to driver performance failures.

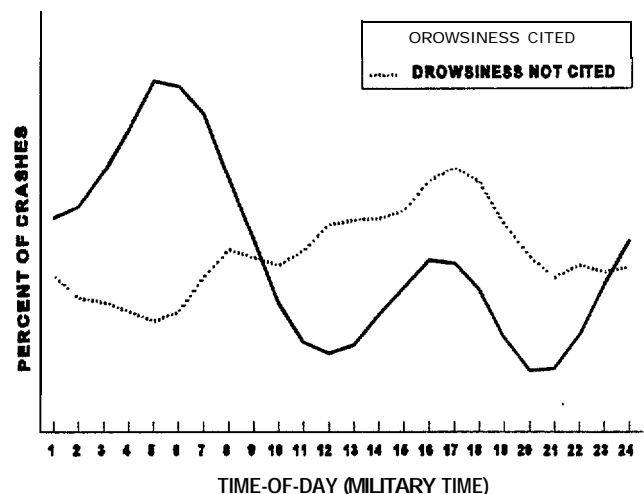


Figure 3. Time-of-Day Comparison Between “Drowsiness-Cited” and “Drowsiness-NotCited” Pure DOOL Crashes; 3-Hour Rolling Averages. source: 1989-93 GES

Development of In-Vehicle Countermeasures

NHTSA's drowsy driver research program, involving a number of related projects, focuses on the development of a vehicle-based driver drowsiness detection system. This system entails continuous, unobtrusive measurements of driver performance (e.g., steering wheel movements, lateral lane position measures), data processing to "decide" whether the driver is drowsy, and warning/alerting signals presented to the driver. Direct, unobtrusive driver psychophysiological measures (e.g., devices to detect excessive eye closures associated with drowsiness) could also be integrated into the measurement/decision regimen. **Figure 4** illustrates this countermeasure concept. The promising potential of performance monitoring is demonstrated in **Figure 5**, which shows that driving performance measures (obtained on a driving simulator and combined mathematically) can be used to detect the psychophysiological state of drowsiness, as measured by driver eye closure (Knipling and Wierwille, 1994; Wierwille, Wreggit, and Knipling, 1994). NHTSA is supporting R&D on detection algorithm refinement, sensor development (including both lane position monitors and direct psychophysiological monitors of driver alertness), and on the advisory messages and/or alerting stimuli to be presented to the driver following detection of drowsiness. Laboratory research focusing on the separate elements of this countermeasure concept will be followed by system development, test, and evaluation work to determine the effectiveness and practicality of these devices under actual driving conditions.

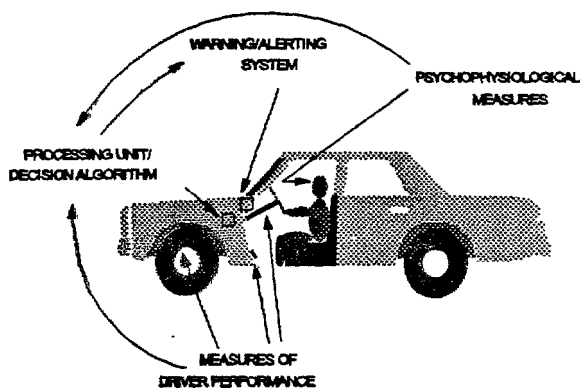


Figure 4. Vehicle-Based Drowsy Driver Detection: simplified System Schematic

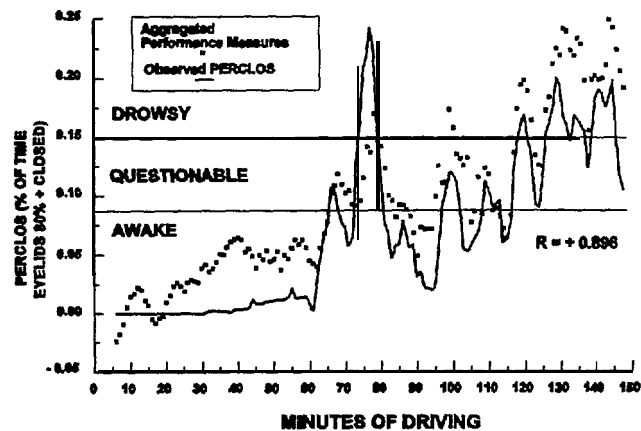


Figure 5. Simulation Data from Sample Sleep-Deprived Driver to Demonstrate Progression of Drowsiness and Feasibility of Performance-Based Detection of Drowsiness

Development of Technologies for Improved Problem Assessment

The agency also plans to gather better problem assessment data through the use of sophisticated, unobtrusive vehicle instrumentation suites to obtain *in situ* data on safety-related driver performance and behavior. NHTSA is sponsoring R&D to design and fabricate a prototype portable Data Acquisition System for Crash Avoidance Research (DASCAR) which will employ miniaturized videos (of the driver and the roadway), psychophysiological monitoring devices (if unobtrusive), and various measures of driving performance. DASCAR-based studies may not only provide direct empirical data on "asleep-at-the-wheel," but may also provide data on the role of drowsiness/fatigue in the huge population of crashes that involve recognition failure and other mental errors (Treat et al, 1979, Najm et al, 1994, Deering, 1994). Specific program plans for these *in situ studies* are to be determined, although it is expected that initial studies will focus on gathering baseline data on normal driving, including the incidence of drowsiness/fatigue and related driving errors and incidents.

References

- American Automobile Association Foundation for Traffic **safety. A Report on the Determination and Evaluation of the Role of Fatigue in Heavy Truck Accidents.** October, 1985.
- Deering, RK., General Motors Safety Center, Crash avoidance technologies to assist the driver, Presentation at the American Society of Civil Engineers Conference **Innovations in Highway Safety A Broad Perspective**, May 17, 1994.
- Fell, D. Safety Update: Problem Definition and Countermeasure Summary: Fatigue. New South Wales Road Safety Bureau, RUS No. 5, July, 1994.
- Harris, W. and Mackie, RR **A Study of the Relationships Among Fatigue, Hours of Service, and Safety of Operations of Truck and Bus Drivers.** Human Factors Research, Inc. Report # 1727-2, 1972.
- Hendricks, D., Bollman, E., Pierowicz, J., Donnelly, B., Weissman, S., Page, J., Scheifflee, T. **Run-Off-Road Collision! Avoidance Using IVHS Countermeasures; Task I Interim Report-**, Calpan Corporation for Carnegie Mellon University, NHTSA Contract No. DTNH22-93-C-07023, October, 1994.
- Knipling, RR and Wierwille, W.W., Vehicle-based drowsy driver detection: current status and future prospects. **Proceedings of the IVHS America 1994 Annual Meeting. b. 245-256**, Atlanta, April 17-20, 1994.
- Miaou, S.P., "Study of Vehicle Scrappage Rates," Oak Ridge National Laboratory, Oak Ridge, TN, August 1990.
- Miller, T.R, et al, **The Costs of Highway Crashes**, Urban Institute, Contract No. DTFH61-85-C-00107, Report No. FHWA-RD-91-055, June, 1991.
- Najm, W.G., Koziol, J-S., Jr., Tijenna, L., Pierowicz, J. A., and Hendricks, D.L. Comparative assessment of crash causal factors **and IVHS countermeasures. Proceedings of the 1994 Annual Meeting of IVHS America. IVHS America. 1994.**
- National Transportation Safety Board. **Safety Study: Fatigue, Alcohol Other Drugs, and Medical Factors in Fatal-to-the-Driver Heavy Truck Crashes.** PB90-917002, NTSB/SS-90/01, February, 1990.
- Office of Technology Assessment, U.S. Congress. **Biological Rhythms: Implications for the Worker**, OTA-BA-463, September, 1991.
- Tilley, D., Erwin, C., and Gianturco, D. Drowsiness and driving: preliminary report of a population survey. SAE **International Automotive Engineering Congress**, Detroit, Report No. 730121, 1973.
- Treat, JR., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, RD., Mayer, RE., Stansifer, RL., and Catellan, N.J. **Tri-Level Study of the Causes of Traffic Accidents: Final Report Volume I: Causal Factor Tabulations and Assessments**, Institute for Research in Public Safety, Indiana University, DOT Publication No. DOT HS-805 085, 1979.
- Wierwille, W.W., Wreggit, S.S., and Knipling, RR Development of improved algorithms for on-line detection of driver **drowsiness. Proceedings of the 1994 International Congress on Transportation Electronics ("convergence '94'3. SAE Paper #94CO40**, Pp.33 1-340, October, 1994.