

COMMERCIAL MOTOR VEHICLE DRIVER FATIGUE AND ALERTNESS STUDY

EXECUTIVE SUMMARY

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The primary source document for this study is the project final report, Commercial Motor Vehicle Driver Fatigue and Alertness Study by Wylie, et. al., dated October, 1996. This Executive Summary is not to be considered a primary source document, but is to be considered an overview document. As such, it necessarily contains abridgements and paraphrasing from a substantially larger and more detailed publication. The reader is urged to consult the Wylie, et. al. final project report as the key reference to the findings of this study.

This document does not constitute a standard, specification, or regulation.

INTRODUCTION

The Driver Fatigue and Alertness Study (DFAS) was the largest and most comprehensive over-the-road study ever conducted on driver fatigue and alertness in North America. It provides extensive information on the alertness, driving performance, and physiological and subjective states of commercial motor vehicle (CMV) drivers as they perform real-life, revenue-generating trips. This Executive Summary overviews the objectives, methods, principal findings, and safety implications of this landmark 7-year study.

STUDY CHRONOLOGY AND PARTICIPANTS

The DFAS was initiated in 1989 by the Federal Highway Administration's (FHWA) Office of Motor Carriers (OMC) in response to a Congressional directive contained in the Truck and Bus Safety and Regulatory Reform Act of 1988. Field data collection was conducted in 1993 and the project was completed in 1996. The overall cost of the study was US\$4.45 million.

The DFAS was both a public-private and an international partnership. In addition to the funding provided by the FHWA, the Trucking Research Institute (TRI) of the American Trucking Associations Foundation and Transport Canada funded a significant portion of the data collection and analysis effort. The TRI, the National Private Truck Council, the International Brotherhood of Teamsters, and the Owner-Operator Independent Drivers Association provided considerable input in public forums. These organizations, as well as the Canadian Trucking Association and the Private Motor Truck Council of Canada, helped recruit motor carriers and drivers and provided technical and operational support to the research effort. Over-the-road data were collected both in the U.S. and Canada. Numerous organizations and individuals shared their views and suggestions regarding the study with the project team during publicly-announced consultation sessions and/or individual discussions.

Essex Corporation, Columbia, Maryland, was the principal research organization conducting this study. Supporting organizations included the Scripps Clinic and Research Foundation of La Jolla, California; Miller Ergonomics of Imperial Beach, California; Deaconess Hospital, St. Louis, Missouri; and the Sleep Disorders Centre of Metropolitan Toronto, Toronto, Ontario, Canada. Three motor carriers provided drivers, vehicles, and the real world less-than-truckload (LTL) operational setting for the study.

PROJECT PUBLICATIONS

Four principal publications have been produced to report the findings of this study:

- A 6-page “**Highlights**” provides background and a top-level overview of the study and its findings.
- A 15-page **Executive Summary** [this document].
- A 59-page **Technical Summary** provides a moderately-detailed account of the study. This and the above two documents are currently available at no charge from

Office of Motor Carriers, FHWA, HCS-30,400 Seventh Street, SW, Room 3 107,
Washington, DC 20590, telephone (202) 366-2981, fax (202) 366-8842.

Transportation Development Centre, Transport Canada, 800 Rene Levesque Blvd.
W., 6th Floor, Montreal, Quebec H3B 1X9 Canada, fax (514) 283-7158, e-mail
tdccdt@tc.gc.ca.

- An approximately 500-page **Technical Report** provides comprehensive and detailed information and data. The Technical Report is expected to be published in late 1996 or early 1997. It may be purchased from the National Technical Information Service, Springfield, VA 22161, telephone (703) 487-4650, e-mail:
(prepaid orders) orders@ntis.fedworld.gov; (inquiries) info@ntis.fedworld.gov

BACKGROUND

Driver fatigue is a safety issue of special concern to CMV transportation. Under current U.S. Federal hours-of-service (HOS) regulations, CMV drivers may drive up to 10 hours after a mandatory 8-hour off-duty period. In Canada, the maximum driving time is 13 hours. Many CMVs often run at night, and drivers sometimes have irregular and unpredictable work schedules. Most of their mileage is compiled during long trips on Interstate and other limited-access highways. Because of the CMVs' high annual mileage exposure (often 5-10 times that of passenger vehicles) and other factors, commercial drivers' risk of being involved in a fatigue-related crash is far greater than that of non-commercial drivers -- even though CMV drivers represent a relatively small proportion of all drivers involved in fatigue-related crashes. In addition, many other crash causation factors, such as alcohol use, speeding, and other unsafe driving acts, are generally less common in crashes involving commercial drivers. Thus, fatigue is a relatively larger concern for these CMV drivers and their vehicles.

HISTORY OF DOT'S FATIGUE FOCUS

The maximum amount of time that CMV drivers, operating in U.S. interstate commerce, may drive their vehicles is specified in Title 49, Code of Federal Regulations, in Part 395. (In Canada, it is the federal "Commercial Vehicle Drivers Hours of Service Regulations, 1994"; SOR/DORS/94-716, 15 November 1994.) The U.S. regulations were originally developed in 1935 by the Interstate Commerce Commission (ICC) to counteract perceived unsafe driver scheduling practices. In 1938, the ICC requested the U.S. Public Health Service to conduct an investigation into CMV HOS in interstate commerce. This was the first scientific study to address driver fatigue as related to HOS. The Public Health Service study supported the need for regulatory limitation of HOS to help ensure highway safety. In 1967, the ICC's responsibilities concerning CMV driver and vehicle safety were transferred to the Bureau of Motor Carrier Safety (now OMC) of the FHWA, an agency within the then newly-created U.S. Department of Transportation (DOT).

The DOT conducted three studies on CMV driver fatigue between the 1970s and the present. None resulted in changes being made to the Federal HOS regulations. In 1988, the Congress directed the DOT to conduct research to determine the relationships among HOS regulations, driver fatigue, and the frequency of serious accidents involving CMVs. Also in 1988, the FHWA hosted a Symposium on Truck and Bus Driver Fatigue, which brought together experts from the motor carrier industry, the scientific and medical communities, law enforcement, and public policy. The DFAS was initiated in response to this Congressional directive and its design was based upon Symposium recommendations. The study began in 1989.

In the 1990s, driver fatigue has continued to be a major industry and public safety concern. The 1995 FHWA-sponsored Truck and Bus Safety Summit, attended by over 200 national leaders in CMV and highway safety, including a large contingent of drivers, identified driver fatigue as the top priority CMV safety issue. Accordingly, the fatigue issue dominates current FHWA-sponsored human factors research on CMV driving safety.

STUDY OBJECTIVES

The primary goal of the Driver Fatigue and Alertness Study was to observe and measure the development and progression of driver fatigue and loss of alertness, and to develop countermeasures to address it, through a field study undertaken within the framework of a realistic driving environment. To accomplish this goal, several objectives were established:

- To establish measurable relationships between CMV driver activities and physiological and psychological indicators of fatigue and reduced alertness.
- To identify and evaluate effectiveness of those alertness-enhancing measures that legally may be used by CMV drivers. Approximately 500 drivers were surveyed in 4 locations (west coast, east coast, midwest, southeast). The FHWA will release the results of this work separately from the main study report, probably in the late fall of 1996.
- To provide a scientifically valid basis to determine the potential for revisiting the current HOS requirements, which have been essentially unchanged for more than 50 years.

Secondary goals of the research were to investigate the potential for utilizing elements of the vehicle- and driver-based measurements in the development of a system for monitoring or predicting changes in driver alertness; to identify an effective subset of data types to improve the efficiency and economy of conducting future fatigue research in field settings; and to provide a data set that could be used for validating future fatigue research using driving simulators.

METHODOLOGY

The methodology and conduct of the DFAS reflected the research objectives described above. The study investigated, in an operational context, a number of work-related factors thought to be related to the development of fatigue and loss of alertness and degraded performance in CMIV drivers. These factors included:

- the amount of time spent driving during a work period,
- the number of consecutive days of driving,
- the time-of-day when driving took place,
- the number of hours spent in principal sleep periods, and
- schedule regularity.

Subjects

Eighty (80) properly qualified male CMV drivers between the ages of 25 and 65 served as subjects in this study. Drivers had to have at least one year of experience driving Class 8 (33,001 pounds and over) tractor trailer combination vehicles and they had to be medically qualified and free from controlled substances and alcohol.

Design

The study employed a between-subjects design involving four driving schedule conditions. Four different groups of 20 subjects drove in the following schedule conditions, selected to represent four contrasting driving schedules in terms of fatigue-related factors such as time-on-task, schedule regularity, and day versus night driving:

- **Condition 1: lo-hour “baseline” daytime (C1: lo-hour daytime):** lo-driving-hour turnaround route, starting at about the same time (10:00) each morning for 5 consecutive days.
- **Condition 2: lo-hour “operational,” or rotating (C2: lo-hour rotating):** 1 O-driving-hour turnaround route, starting about 3 hours earlier each day for 5 days. The first trip began at about 10:00
- **Condition 3: 13-hour nighttime start (C3: 13-hour nightstart):** 13-driving-hour turnaround route, starting at about the same time (23:00 on average) each night for 4 consecutive nights.
- **Condition 4: 13-hour daytime start (C4: 13-hour daystart):** 13-driving-hour turnaround route, starting about the same time each day (13:00 on average) for 4 consecutive days.

Altogether, there were 360 trips and about 4,000 hours of driving, distributed more or less evenly across the four conditions. Conditions 1 and 2 took place in the U.S. between the cities of St. Louis and Kansas City, Missouri. Conditions 3 and 4 took place in Canada between the cities of Montreal, Quebec and Toronto, Ontario. The study design was developed to comply with existing U.S. and Canadian hours-of-service regulations.

The four schedules provided different amounts of time off between trips. Condition 1 provided about 11 hours off, while the other three conditions provided about 8 hours off.

Vehicles and Instrumentation

Conventional Class 8 truck tractors from each participating motor carrier were outfitted with on-board monitoring equipment and a data acquisition computer. Tractors included both single-drive-axle and tandem-drive-axle designs. Trailer configurations included both single semitrailers (45', 48', and 53') and twin 28' trailers. All participating drivers were completely familiar with their assigned vehicles.

Driver and Driving Measures

Numerous measures were taken of drivers' physiology, alertness, and performance during driving and of their physiology during off-duty sleep. Many data elements were collected simultaneously, and all data were time-stamped to aid in analysis. Measures collected for each subject included:

- Driving task performance
 - Lane tracking (collected using a device that measured the tractor's lateral position relative to lane markings)
 - Steering wheel movement
- Driving speed and distance monitoring (to aid in data analysis)
- Performance on three surrogate tests of tasks related to safe driving performance. Drivers took the tests before starting their runs, after they reached the turnaround point halfway through their trip (and, during the two 10-hour conditions, before the return trip commenced to study the effects of a break), and after the run was completed. The tests were self-administered while the vehicle was stopped via a CRT display mounted in the truck cab. Each administration of the set of tests took about 18 minutes. The surrogate tests were:
 - Code Substitution (a cognitive test involving number/letter substitution)
 - Critical Tracking Test (a test of hand-eye coordination, requiring a pointer moving in an unpredictable manner to be kept at the center of a display)
 - Simple Response Vigilance Test (a test of vigilance and reaction time).
- Continuous video monitoring
 - Face video (to permit judgments of alertness based upon eyelid droop and facial expression and muscle tone; an infrared illuminator was used to permit night monitoring)
 - Road video (forward-looking video recording to permit reconstruction of driving and traffic events).
- Physiological measures
 - Polysomnography (PSG) during sleep
 - Electroencephalogram (EEG) using clinical-type scalp electrodes
 - Electrooculogram (EOG); electrodes placed at left and right outer canthi (corner of the eyes)
 - Electromyogram (EMG); electrodes placed on chin
 - Respiratory airflow (nasal sensor)
 - Respiratory effort (sensors on chest)
 - Oxygen saturation of arterial blood (finger probe).
 - PSG during driving (EEG and EOG only).
 - Body temperature during waking hours (obtained using an infrared ear probe)
 - Electrocardiography (ECG) during driving and sleep.
- Driver-supplied information
 - Pre-participation questionnaire on sleep habits -
 - Daily log (stops, meals, noteworthy driving events, etc.)
 - Stanford Sleepiness Scale rating (a self-assessment of fatigue and mood).
- Tractor cab environment (temperature, relative humidity, 8-hour concentrations of carbon monoxide and nitrogen dioxide)

Data Analysis

The study developed a massive database which covers more than 200,000 miles of driving. It includes some 4,000 hours of video data, 9,000 hours of physiological recordings, and 700 megabytes of real-time truck computer records. Close to a year was needed to clean the raw field data and to enter them into a complete project data base. Standard protocols were used for converting raw data into meaningful metrics; for example, the PSG sleep data were scored manually using standard clinical criteria to assign sleep stages. Statistical analysis focused on comparisons of group means to evaluate the effects of driving schedule (and related factors such as hours of sleep) for a variety of dependent measures of driver alertness and performance (as listed above). In addition, instances of drowsiness during driving were identified and analyzed. Initial comprehensive reviews were done by two research teams working independently to assess the physiological and driving-performance data. The results of these reviews were then compared to clearly document these events.

Strengths and Limitations of the Methodology

The strengths of the methodology of the DFAS were in its naturalistic approach (i.e., data collected during revenue-generating runs), the enormous volume of data collected, and in the comprehensiveness of the measurements. The limitations of the study relate primarily to the lack of full control over the full range of conditions affecting alertness and fatigue and the inability to isolate some factors due to unavoidable confounding of variables, a consequence of the naturalistic approach to the study. For example, a comparison of Condition 1 (1 O-hour daytime) and Condition 3 (13-hour nightstart) shows that the conditions differ in several important ways: number of continuous hours of driving, percent of night driving, and number of hours off-duty. In addition, the combination of the inherent variability of the real world environment and the between-subjects design meant that there was more uncontrolled variability (“noise”) in the data than would be found in a study performed within a laboratory setting or a study-controlled driving environment, or one employing a within-subjects design. The study’s analysis methodology included assessments of the consistency and inconsistency of results from different measures.

RESULTS AND DISCUSSION

Project findings are reported below as they relate to major issues.

Time-of-Day of Driving

The strongest and most consistent factor influencing driver fatigue and alertness in this study was time of day. Drowsiness, as observed in video recordings of the driver’s face, was markedly greater during night driving than during daytime driving. Peak drowsiness occurred during the 8 hours from late evening until dawn.

Night driving (e.g., from midnight to dawn) was associated with worse performance on four

important criteria (proportion of video-drowsy analysis periods, average lane tracking standard deviation, incremental differences in Code Substitution test scores between the outbound and inbound segments of a trip, and average physiologically-measured total sleep obtained during the principal sleep period prior to a trip). Time of day was a much better predictor of decreased driving performance than hours of driving (time-on-task) or the cumulative number of trips made.

Duration of Driving

Hours of driving (time-on-task) was not a strong or consistent predictor of observed fatigue. Most notably, there was no difference in the amount (prevalence) of drowsiness observed in video records of comparable daytime segments of the 10-hour and the 13-hour trips. Nighttime segments could not be similarly analyzed because the study design did not provide for this comparison.

Lane tracking performance was better in the 10-hour than the 13-hour conditions. The reasons for this are not completely clear because of confounding factors associated with different routes and vehicles.

In the surrogate tests, cognitive performance (via Code Substitution) was better in the 10-hour conditions. Vigilance and reaction time (via Simple Response Vigilance Test) were better in the 13-hour conditions (probably because of loss of display contrast associated with greater amounts of sunlight in the 10-hour conditions). Hand-eye coordination (via Critical Tracking Test) did not show condition-related variation.

There was little correlation between Stanford Sleepiness Scale self-ratings and objective performance test scores. However, self-ratings of fatigue level on the Stanford Sleepiness Scale correlated positively with time-on-task, indicating that drivers may have the feeling of increasing fatigue with increasing time-on-task even if there are no strong performance changes.

Cumulative Fatigue Across Days

There was some evidence of cumulative fatigue across days of driving. For example, performance on the Simple Response Vigilance Test declined during the last days of all four conditions. Also, drivers tended to rate themselves as more fatigued across multiple trips. However, cumulative number of trips was neither a strong nor consistent predictor of fatigue across different measures. Although more apparent drowsiness was noted in video recordings made in the last two trips of Condition 2 (10-hour rotating), those trips were, on the average, driven at night (see statement above concerning night driving). The Stanford Sleepiness Scale self-ratings of sleepiness increased as drivers progressed through successive trips within Condition 2, but the trends were unclear in Condition 3 (13-hour nightstart) and Condition 4 (13-hour daystart).

Daily Principal Sleep Periods

Overall, drivers obtained about 2 hours less time in bed and 2.5 hours less actual sleep than their reported “ideal” daily amount of sleep. The drivers reported an average “ideal” 7.2 hours per principal sleep period on a questionnaire completed before their first sleep at the sleep lab; the

average observed time in bed over the course of the study was 5.2 hours. (Although the drivers reported what they considered to be their “ideal” sleep time, they were not asked, and it is not known, whether they usually obtained this stated amount.) For the four conditions, the average times in bed and clinically-measured sleep times were:

- Condition 1 (10-hour daytime): 5.8 hours in bed, 5.4 hours asleep.
- Condition 2 (10-hour rotating): 5.1 hours in bed, 4.8 hours asleep.
- Condition 3 (13-hour nightstart): 4.4 hours in bed, 3.8 hours asleep.
- Condition 4 (13-hour daystart): 5.5 hours in bed, 5.1 hours asleep.

The observed shortfall could have been due, in part, to a reduction in free time due to requirements of the study protocol. The study setting also created an opportunity for socializing with other drivers that might not exist in normal driving. In addition, some drivers did not always organize their off-duty time wisely to obtain the maximum possible sleep. Time-in-bed was lowest for the three Conditions (2,3, and 4) that permitted the least off-duty time (about 8.6 to 8.9 hours on average, excluding time required for the study protocol). Nevertheless, even in Condition 1, which permitted about 10.7 hours off-duty between trips, the average time-in-bed and time asleep were only 5.8 and 5.4 hours, respectively.

The lower ratio of sleep time to time in bed for Condition C3 (13-hour nightstart) may reflect circadian disruptions of sleep pattern in comparison with the other conditions. This condition was the only one that consistently required drivers to sleep during the daytime.

Quantity and Quality of Sleep Obtained

The quantity of sleep obtained by the subjects in their principal sleep periods was low. As noted above, drivers obtained an average of about 2 hours less sleep than their daily “ideal” requirements. The average time-in-bed during the principal sleep period (i.e., not including naps, which are addressed below) was 5.2 hours versus a self-reported daily “ideal” of 7.2 hours. The shortest average time-in-bed (4.4 hours) was associated with Condition 3 (13-hour nightstart); these drivers had about 8.6 off-duty hours daily beginning at about noon.

All of the drivers obtained efficient, normally-structured sleep as judged by formal clinical criteria. Of the 5.2 average hours in bed, the drivers were actually asleep for an average of 4.8 hours. The average sleep efficiency (sleep time/time-in-bed) was 0.92; levels above 0.90 are often observed in people who have no trouble sleeping and in people who are sleep deprived. The average amount of time awake after sleep commenced was 25 minutes; this value is considered low relative to values in the normal range (less than 60 minutes for adult men) and is also consistent with reduced time in bed and with sleep deprivation.

The requirements of the study may have contributed somewhat to driver sleep deprivation, but the overall effect appears to be due to a combination of insufficient opportunity for sleep, and the

failure of drivers to place a high enough priority on obtaining sufficient sleep.

Drowsiness During Driving

Video ratings were much more sensitive for detecting drowsiness while driving than were polysomnographic (PSG) measures. The 4,000 hours of video recordings were systematically sampled at 30-minute intervals. Drowsy episodes discovered were judged in 6-minute periods from 30 minutes before to 30 minutes after their occurrence. Approximately 4.9% of the sampled face video segments were scored as drowsy based on trained reviewers' assessment of such factors as eye movement, eyelid position, yawns, stretches, and startles. The proportions of video data scored drowsy were much greater at night than during the day or evening. Fourteen percent of drivers accounted for 54% of all observed drowsiness episodes.

All EEG and EOG data were analyzed. PSG analysis indicated that there were two trips, involving different drivers (an incidence of about 0.6 % of observed trips and about 2.5 % of observed drivers), that included a number of intermittent episodes that were identified as PSG-Drowsy Driving. These periods amounted to just over 19 minutes out of the 244,667 minutes of driving analyzed (0.008%). During these periods, the drivers' data presented EEG and EOG patterns that would have been consistent with clinical criteria for Stage 1 sleep (the initial, shallowest, sleep stage) if the drivers had been in bed in a dark room. Face-video records during these periods also showed driver drowsiness. The EEG measurement may have revealed a worse (by comparison with the face-video judgments) and infrequently-occurring condition. However, these differences may be reflective of the relative sensitivities of the two methods of detecting drowsy driving.

A comparison of steering and lane tracking performance for video-rated drowsy versus non-drowsy epochs indicated that drowsiness was associated with more erratic steering (greater steering wheel angle variability) and poorer lane tracking (increased standard deviation of lane position), both of which have obvious implications for driving safety.

Not surprisingly, there was a negative correlation between the length of the principal sleep period and amount of drowsiness during the next driving trip (e.g., more sleep leads to less drowsiness). However, it was not possible to estimate the "normal" level of drowsiness during driving since there were no conditions where all drivers obtained adequate sleep.

Although there were video, PSG, and driving performance indications of driver drowsiness, there were no crashes during the study.

Napping

Of the 80 drivers, 35 (44%) took at least one nap during a duty cycle that contained clinically-scorable sleep. Drivers who elected to nap increased their sleep obtained in principal sleep periods by an average of 27 minutes which amounted to an **11%** increase in average daily sleep time. Drowsiness, as evident in face video recordings, was often a precursor to the driver deciding to take a nap. Thus it appeared that this behavior was replacement or compensatory napping, taken in response to self-perceived sleepiness.

Because 45 of the drivers did not nap, and there were only 63 naps taken over the 360 trips in the study, no analyses were performed to determine whether these driver naps resulted in post-nap improvement in alertness and performance. This is one of many important questions which might be addressed by future analysis of the data collected in the DFAS.

Effects of Mid-Trip Breaks

In the 1 O-hour conditions (Conditions 1 and 2) drivers self-administered the surrogate performance tests both at the beginning and the end of their mid-trip turnaround break. The only test demonstrating improved post-break performance was the Code Substitution test. The other performance tests failed to show a statistically-significant recovery effect.

Driver Self-Awareness of Fatigue

There was little correlation between driver subjective self-ratings of alertness/sleepiness and concurrent objective performance measures. It appears that drivers are not very good at assessing their own levels of alertness; there was a tendency for drivers to rate themselves as more alert than the performance tests indicated.

On the other hand, there was a positive correlation between self-ratings of fatigue and both the number of hours of driving within a trip and the cumulative number of trips made. Perhaps these factors affected the experience of fatigue, reflecting increasing stress or compensatory effort rather than objective performance. Or, perhaps drivers were basing their self-ratings in part on a logical expectation that these factors would increase fatigue and they would thus be led to respond in kind as they selected their Stanford Sleepiness Scale rating. If the latter explanation were true, drivers would in effect be saying to themselves, "If I've been driving for a long time, then I must be tired."

Self-ratings did not correlate significantly with trip segments ranked according to percent of night driving, even though performance measures showed significantly reduced performance at night than during the day. If the "expectation" explanation of driving self-ratings in the previous paragraph is correct, a disturbing corollary would be that drivers had no expectation that night driving would be associated with reduced performance, when in fact these performance reductions are significant.

Individual Differences in Driver Susceptibility to Drowsiness

There were large individual differences among drivers in levels of alertness and performance. For example, there was a wide variation in the total number of episodes judged drowsy in the video records. Thirty-six percent (36%) of the drivers were never judged drowsy; of the remainder, 77% (49% of the total) were judged drowsy 10 or fewer times, and 23% (15% of the total) were judged drowsy more than 10 times. Among the drivers with more than 10 drowsiness episodes, the number of drowsy episodes ranged from 12 to 40, with an average of 22 episodes during their 4-5 day participation period.

A further illustration of the wide individual differences among drivers is the fact that 11 of the 80 drivers (14%) accounted for 54% of all observed drowsiness episodes.

This study did not track the subjects over extended periods of time to determine if the same drivers showing frequent drowsiness during the week of the study would show frequent drowsiness weeks or months later. Thus, it cannot be discerned whether the observed individual differences were reflective of driver *traits* (i.e., long-term, stable individual differences in physiology and/or performance) or of driver *states* (short-term differences related to recent sleep or other transient events). Of course, both traits and states may be operative. Future research should address the trait versus state issue because it has implications for the potential effectiveness of improved driver selection, scheduling, and training as fatigue countermeasures.

Comparisons Among Driving Schedules

In general, differences in driver alertness among the four driving schedules (study conditions), as observed and measured by various driving performance and physiological means, appeared to reflect differences in amount of night driving, rather than other factors such as differences in continuous driving time. There was no difference in the amount of drowsiness observed in the video data during comparable (i.e., daytime) trip segments of the 10-hour and 13-hour trips. Night-driving segments could not be similarly compared on a trip-by-trip basis because only the last two trips of Condition 2 (10-hour rotating) were driven through the night.

Condition 3 (13-hour nightstart) was associated with the shortest sleep latencies (time required to fall asleep after going to bed), further indicating that these drivers received less sleep than they needed. Further, the small amount of sleep obtained by Condition 3 drivers may have exacerbated the degraded performance observed at night in the study, since those drivers performed the greatest proportional amount of night driving.

Sleep Apnea

Although this study was not designed to determine a population prevalence, analysis of subject sleep revealed that two of the 80 drivers (2.5%) had clinically-diagnosable apnea, a sleep disorder characterized by breathing cessations. The driving performance of these two individuals was not statistically different from that of other comparable drivers in the study.

Age and Fatigue

No significant relationships were found between driver age and fatigue. There were no consistent differences between older and younger drivers in terms of observed drowsiness, frequency of naps, self-ratings, or driving performance. Older drivers performed more poorly on the Code Substitution test than younger drivers, but this effect was not fatigue-related. In order to control for this effect, the Code Substitution data were grouped by driver age so that the general age difference in performance did not confound other comparisons.

Study Findings Concerning Countermeasures

Although the DFAS was not designed specifically to support the development of technological countermeasures, the findings of the study are supportive of their feasibility. Of the surrogate

performance tests employed, the Simple Response Vigilance Test demonstrated the most promise in detecting fatigue as it might develop during the course of a trip or cumulatively across trips. Although the sensitivity of this test to ambient light level, as found in this study, must be reduced, surrogate tests might be used as part of fitness-for-duty testing approaches to detecting driver fatigue.

Changes in driving performance, measured by increased variability in steering and lane tracking, were shown to be correlated with drowsiness as judged in video observations of the driver's face. The correlation between drowsiness and degraded driving performance supports the concept of continuous monitoring of driver performance to detect fatigue. A related and complementary approach to performance monitoring is to directly measure psychophysiological changes such as the eyelid droop seen in face videos of drowsy drivers or various PSG indices of reduced alertness. The DOT and other agencies and organizations are sponsoring a wide range of research on technological fatigue-detection and prevention countermeasures. Fitness-for-duty (readiness-to-perform) testing and continuous driver monitoring approaches are both being assessed. At the same time, driving performance is also influenced by the design and condition of the roadway, by the characteristics of the vehicle being driven, and by the number and location of other vehicles sharing the roadway. Those influences must be accounted for in the development of continuous-monitoring systems.

The study also sought to identify any behavioral methods used by drivers to ward off fatigue. Napping was a frequent driver-initiated response to drowsiness and fatigue. The alertness-enhancing effects of napping have been demonstrated in other operator performance settings (e.g., commercial aviation) and should be the subject of future research, including additional analysis of the DFAS database. Other methods will be reported in the countermeasures survey.

The highly significant time-of-day effects on fatigue demonstrate that scheduling may be an important countermeasure to CMV driver fatigue. From the driver fatigue and alertness standpoint, the optimal schedule is one that appropriately manages night driving. There are no known highway transportation hours-of-service regulations in the world that address time-of-day effect, even though shiftwork literature for many years has pointed out a strong relationship between time of day and accidents and incidents.

It cannot be concluded, however, that shifting truck traffic to daylight hours would result in lower accident rates. This measure would increase daytime traffic congestion, possibly with a corresponding increase in accidents, and would further increase the risk of accidents with passenger vehicles which are more vulnerable in accidents with trucks because of their difference in mass. Research is needed to establish the relative risks of accidents between day and night driving for a variety of road and vehicle types, and levels of traffic density, to establish the net impacts on highway safety of day/night scheduling practices.

Another key to enhanced scheduling at the fleet level may be the finding of large individual differences in susceptibility to drowsiness while driving, as noted in this study. It appears that some drivers may be much better than others at maintaining alertness in the long-haul CMV environment, especially at night -- a potential basis for driver selection and assignments of runs should future research prove that these individual differences are consistent over time.

Implications for Educational Approaches

Two major project findings relevant to driver education were the generally inadequate amounts of sleep obtained by the driver subjects and the strong tendency for drowsiness to be most associated with nighttime circadian effects. Drivers need to be educated about how to obtain more sleep, especially if they will drive at night. Further, study findings showed that drivers were generally poor judges of their own levels of fatigue/alertness. This finding indicates a need to train drivers to better assess their current levels of fatigue while driving, perhaps by learning to become more conscious of changes in their physical state and subtle changes in their driving performance.

ASSESSMENT OF RESULTS FOR FATIGUE MANAGEMENT

There is no quick fix and no single solution to the fatigue problem. Sleep is the principal countermeasure to fatigue. All drivers need to ensure that they obtain adequate sleep. Drivers must also be afforded the opportunity to obtain adequate sleep.

Changes in the hours-of-service regulations alone will not solve the fatigue problem. Much can be done to address driver fatigue through a combination of innovative hours-of-service regulation and enforcement, education, driver work scheduling, innovative fatigue management programs, driver screening, fitness for duty and alertness monitoring systems, and additional research.

Partnerships among government, industry, drivers, safety groups, the scientific community, and shippers are needed for effective solutions to the commercial motor vehicle driver fatigue problem.

FUTURE DIRECTIONS

The DFAS demonstrated that it is possible to conduct a field study with substantial numbers of commercial drivers (80) hauling revenue freight on many trips (360), employing instrumentation to record numerous aspects of vehicle control, surrogate test performance, driver physiology, face and road video, and sleep studies for each principal sleep period. This was accomplished without any motor vehicle crashes or other harm to the study subjects or other participants. The data collected have been used to document a number of fundamental characteristics of driver fatigue and alertness and the archived DFAS database will continue to support analyses of additional questions over the coming years.

Driver drowsiness/fatigue has become the dominant human factors research issue relating to CMV transportation. For example, the FHWA/OMC currently sponsors more than a dozen research and education/outreach projects relating to CMV driver drowsiness/fatigue. Recently completed, current, or planned fatigue-related research includes studies on work, rest and recovery; sleep apnea; multi-trailer vehicle driver stress and fatigue; highway rest areas; use of on-board recorders for hours-of-service and other regulatory compliance; driver fitness-for-duty testing; other technological fatigue countermeasures; fatigue education for driver and other CMV-related personnel; fleet-based driver wellness; the role of shippers and receivers in HOS violations;

scheduling practices and fatigue; safety analysis of HOS “restart” options; sleeper berth usage and fatigue; local/short-haul driver fatigue; loading/unloading and fatigue; and improved crash causation analysis. Many of these studies will build upon the research techniques developed, practical lessons learned, and scientific knowledge gained from the DFAS.

A separate report, to be published under the sponsorship of Transport Canada and the Canadian Trucking Research Institute of the Canadian Trucking Association, will present the results and analysis of an additional field study that was performed in coordination with this one. The data base in the Canadian study covers an additional 55 trips performed under various driving and days-off schedules lasting up to 10 days. That study will provide additional information to build on the results of this study, including results on the influence of different durations of multi-day off-duty periods.