U.S./CANADA STUDY OF
COMMERCIAL MOTOR VEHICLE
DRIVER FATIGUE AND ALERTNESS

by

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The primary source document for this technical paper is the FHWA report no. FHWA-MC-97-002, Transport Canada report no. TP12875E, titled “Commercial Motor Vehicle Driver Fatigue and Alertness Study” by Wylie et al., October 1996.
The Commercial Motor Vehicle (CMV) Driver Fatigue and Alertness Study was the largest and most comprehensive over-the-road study of its kind ever conducted in North America. Its primary purposes were to establish measurable relationships between CMV driver activities and physiological and psychological indicators of fatigue and reduced alertness and to provide a scientifically valid basis to determine the potential for revisiting the 60-year-old hours-of-service regulations.

A number of work-related factors thought to influence the development of fatigue, loss of alertness and degraded performance in CMV drivers was studied within an operational setting of real-life, revenue-generating trips. These 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; and schedule regularity.

It was found that the strongest and most consistent factor influencing driver fatigue and alertness 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. The number of hours of driving (time-on-task) was not a strong or consistent predictor of observed fatigue.

Other study findings noted that the number of driving periods was not a strong or consistent fatigue predictor; that there was a low correlation between drivers’ subjective self-ratings of alertness/sleepiness and concurrent objective performance measures; and that there was a large difference between the amount of sleep drivers reported as their “ideal” and the amount they obtained during principal sleep periods in the study setting.

While there is no single solution to 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.

STUDY CHRONOLOGY AND PARTICIPANTS

The Commercial Motor Vehicle Driver Fatigue and Alertness Study 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 study 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 Research Institute of La Jolla, California, Miller Ergonomics of Imperial Beach, California, Deaconess Hospital, St. Louis, Missouri, and the Sleep Disorders Centre of Metropolitan Toronto, Ontario. Three motor carriers provided drivers, vehicles, and the real world less-than-truckload (LTL) operational setting for the study.

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.

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 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 Driver Fatigue And Alertness Study 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 CMV 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. All drivers had to have at least one year of experience driving Class 8 tractor trailer combination vehicles (33,001 pounds and over). They had to be healthy and free from controlled substances and alcohol, and have no documented medical history of sleep disorders. All drivers were volunteers and each was given an examination by a physician.

Design
The study employed a between-subjects design involving four (4) 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**: 1 O-hour “baseline” daytime: 10-driving-hour turnaround route, starting at about the same time (10:00) each morning for 5 consecutive days.

- **Condition 2**: 1 O-hour “operational,” or rotating: 10-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: 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: 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 (1 O-hour daytime start) 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 three surrogate tests were:
  - Code Substitution (a cognitive test involving number/letter substitution)
  - Critical Tracking Task (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 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); electrode placed on chin
    - Respiratory airflow (nasal sensor)
    - 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).
Database and 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 database.

Standard protocols were used for converting raw data into meaningful metrics. For example, the PSG sleep data were scored manually using standard clinical criteria (according to Rechtschaffen and Kales methods) to assign sleep stages. Each record was reviewed by a trained polysomnographic technologist. Scoring consistency among the various technologists was assured by re-scoring randomly selected records, group discussion of difficult records, and review of data by a diplomate of the American Board of Sleep Medicine.

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 earlier). In addition, instances of drowsiness during driving were identified and analyzed. Initial comprehensive reviews of the database for potential drowsiness periods were done by two research teams assessing the EEG and driving-performance data independently. The results of these reviews were then compared to clearly document these events.

Because of the large amount of technical data that were generated and presented in the final technical report (of over 500 pages) on this research, this paper concentrates on project findings concerning the major CMV driving issues rather than statistical analysis results.

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. 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. 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 (Figure 1).

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).

Duration of Driving

Hours of driving (time-on-task) was not a strong or consistent predictor of observed fatigue (Figures 2 and 3). Most notably, there was no difference in the amount (prevalence) of drowsiness observed in video records of comparable daytime segments of the IO-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 IO-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 Task) 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, such as can be seen in Figure 4 which shows the proportion of epochs judged drowsy as a function of time of day for the four trips of Condition C3 (13-hour nighttime start) and C4 (13-hour daytime start). 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 (10-hour rotating), but the trends were unclear in Condition 3 (13-hour nighttime start) and Condition 4 (13-hour daytime start).
Figure 2. Proportion of epochs judged drowsy as a function of time elapsed in Condition 3 (13-hour nighttime start)

Figure 3. Proportion of epochs judged drowsy as a function of time elapsed in Condition 4 (13-hour daytime start)
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 8.7 to 9.1 hours on average, excluding time required for the study protocol). Nevertheless, even in Condition 1 (10-Hour Daytime), which permitted about 10.8 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 3 (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 8.7 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 have a substantial sleep debt. 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 debt.

The requirements of the study may have contributed somewhat to low driver sleep times, 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 (Rechtschaffen and Kales) 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, nor were there known, documented “near-misses” noted on the video records reviewed.

**Napping**

Of the 80 drivers, 35 (44%) took at least one nap during a duty cycle that contained clinically-storable 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 Driver Fatigue And Alertness Study.

**Effects of Mid-Trip Breaks**

In the 10-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.

An overview of these results is show in Tables 1 and 2 which show Spearman rank order correlation coefficients and associated probabilities for a case study. The drivers’ self-ratings (AVGZSSS) correlated significantly with trip segments ranked primarily in order of hours of driving (HRS-SVCI), and with trip segments ranked primarily according to cumulative number of trips (HRS-SVC3), but the self-ratings did not correlate significantly with trip segments ranked according to percentage of night driving (PCTNIGHT).
Table 1. Spearman rank correlation coefficients

<table>
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<th>Criterion Variable</th>
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<th>HRS_SVC2</th>
<th>PCTNIGHT</th>
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<td>AVGZSSS'</td>
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</table>

1) Percent of drowsy epochs; 2) Average lane tracking standard deviation; 3) Code substitution test difference; 4) Average sleep in preceding principal sleep period; 5) Average Stanford Sleepiness Scale rating.

Table 2. Probabilities associated with the correlation coefficients

<table>
<thead>
<tr>
<th>Criterion Variable</th>
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<th>HRS_SVC2</th>
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</table>

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 (Figure 5). 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.

Sleep Apnea

Although this study was not designed to determine a population prevalence, PSG analysis of subject sleep revealed that 2 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 desegregated by driver age so that the general age difference in performance did not
confound other comparisons.

Study Findings Concerning Countermeasures

Although the Driver Fatigue and Alertness Study 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
relation 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. Continuous driver monitoring approaches
need to take into account that 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.

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., aviation) and should be the subject of future research, including re-analysis of the Driver Fatigue and Alertness Study database.

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 are 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. Should research findings indicate that such individual differences are not consistent (i.e., they are easily changeable) that would imply that training solutions may be effective.

**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 night-time circadian effects. Drivers need to be educated 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 CMV driver fatigue problem.