APPENDIX (III)
REVIEW OF SAFETY LITERATURE

(III).1 INTRODUCTION

The purpose of the literature review was twofold: to identify and summarize material published or identified since the preparation of the 2003 RIA, and to identify material that has a bearing on the specific issues considered in proposed revisions to the 2003 HOS regulations. The revisions were specifically concerned with maximum driving time between rest periods, the issue of team driving where the driver works a series of short driving and rest periods and the effectiveness of long "weekend" breaks on accumulated sleep deficits. Much of the material is drawn from a literature survey commissioned by FMCSA specifically for this analysis, supplemented by relevant material identified by ICF staff as the work progressed.

The review is organized into broad subject headings as follows:

- Sleep and Performance Modeling;
- Survey-Type Studies of Truck Driver Fatigue and Performance;
- Instrumented and/or Laboratory Studies of Driver Fatigue and Performance; and
- Truck Crash Risks and Costs.

A brief summary is provided for each paper or report, containing a description of the study and principal findings relevant to the HOS analysis.

(III).2 SLEEP AND PERFORMANCE MODELING

(III).2.1 Steven R Hursh, Daniel P. Redmond, Michael L. Johnson, David R. Thorne, Gregory Belenky, Thomas L. Balkin, William F. Storm, James C. Miller and Douglas R. Eddy "Fatigue Models for Applied Research in Warfighting", Aviation Space and Environmental Medicine, Vol. 75, Number 3 Supplement, 2004.

Description of Study

This paper describes the development and application of a comprehensive model for estimating the performance of personnel as a function of work and sleep schedules. The sleep and performance model, called the SAFTE model (Sleep, Activity, Fatigue and Task Effectiveness) is an outgrowth of an ongoing sleep and performance research conducted at the Walter Reed Army Institute of Research. Earlier, the WRAIR had developed a Sleep Performance model (WRAIR-SPM) based on laboratory tests of vigilance performance as a function of sleep and work schedules. This model was refined in a cooperative effort of several research organizations, and incorporation of research findings from a large number of sources to create the SAFTE model. This model incorporates two of the three main determinants of performance: circadian rhythm effects (both due to travel across time zones and due to the time-of-day of the working period) and sleep deprivation arising out of sleep and work schedules over the past few days. The model does not include time-on-task (TOT) effects. The SAFTE model has been incorporated into a working tool called FAST (Fatigue Avoidance Scheduling Tool) that provides a user-friendly interface to the SAFTE model for evaluating alternative schedules.

Modeling Approach

The core concept behind the SAFTE model is that of a sleep reservoir which individuals draw upon while awake and which is replenished by sleep. The overall structure of the SAFTE model is described below.

Alertness or performance is a function of three inputs:

- The amount of depletion of the sleep reservoir – research shows performance declines to the low level of 25% of that of a fully rested individual after 72 hours continuous wakefulness. A linear relationship between performance and sleep debt is used, although some research results suggest a non-linear relationship. Both the slope and shape of relationship can vary with the test task used to assess performance.

- Sleep inertia effects. Full wakefulness is not attained instantly on awaking. Instead there is a period, typically on the order of 1 to 2 hours, depending on sleep intensity and the current status of the sleep reservoir, during which performance recovers to a peak value, after which the normal decline with reservoir depletion resumes.

- Circadian rhythm effects. As discussed in Section 5.1.1, the circadian cycles affect alertness as a function of time of day and the individual's sleep/waking cycles over the past several days.

The model applies the results of numerous research studies of each effect to provide a continuous estimate performance levels over time. In principal, the model is not limited to one specific performance measure (such as the Psychomotor Vigilance Test (PVT) measure used in both this and the original truck HOS analysis), provided there is a sufficient research base to establish the relationships between task performance and the status of the sleep reservoir.

Replenishment of the sleep reservoir also depends on multiple inputs, as follows:

- Length of sleep. A non-linear function exists between the length of sleep and the amount of replenishment. The per-hour replenishment is less for the first three hours of sleep than later in the sleep cycle. The model also incorporates a factor for fragmented sleep, to quantify the reduction in sleep effectiveness due to frequent wakening, such as from external noise and vibration or a sleep disorder.

- Reservoir depletion level. Generally the lower the sleep reservoir, the greater the restorative effect of sleep. The term sleep intensity is used to quantify this effect.

- Circadian rhythm. Sleep is more effective (higher sleep intensity) around the low points in the circadian rhythm.

As with performance estimates, the SAFTE model applies the results of numerous research studies to estimate reservoir replenishment for a given period of sleep.

The authors conclude by identifying a number of areas where there are unexplained contradictions or anomalies in the available data, and where further research would be useful. One key area is the relationship between the performance metric and the actual demands of a specific task. In the HOS analyses, a relationship was developed between PVT and crash risk from truck driving simulator tests. Similar relationships are needed for other tasks, both to identify the most appropriate measure for a specific task and to establish a relationship for use in practical applications of the model.

(III).3 SURVEY-TYPE STUDIES OF TRUCK DRIVER FATIGUE AND PERFORMANCE

(III).3.1 Arnold, P.K., Hartley, L.R., Hochstadt, D., and Penna, F. "Hours of work, and perceptions of fatigue among truck drivers." (1997). Accident Analysis & Prevention, 29 (4) 471-77.

Description

This paper summarizes the results of a survey conducted with 1,249 truck drivers and 84 management representatives of transport companies. Data was collected in an Australian state which, at the time of the survey, did not restrict driving hours for heavy haulage drivers. Regulations were being discussed to limit driving to 14 hours in any 24-hour period, and restricting driving hours over the week to 72 hours. The aim of the study was to obtain information about hours of work and sleep from drivers operating in an unregulated environment. Drivers were asked to provide details about their driving and non-driving work schedules and the amount of sleep they had obtained in the past week. They were also asked to give an hour-by-hour record of activities, feelings of fatigue, and encounters with dangerous events over the 24 hours prior to the interview. Drivers and company representatives were interviewed about their perceptions about fatigue (e.g., factors perceived to be related to fatigue, causes, management) and whether they felt fatigue was problematic for truck drivers. A definition of fatigue was not provided. The authors concluded the paper by comparing their data on unregulated drivers' perceptions about fatigue to those reported by Williamson et al. (1992) for mainly regulated drivers.

Relevant Findings

- In a 24 hr period approximately 38% of drivers exceeded 14 hours of driving and 51% exceeded 14 hours of driving plus other non-driving work
- Approximately 17% of unregulated drivers exceeded 72 hours of driving in the week. When non-driving work is added, 30% worked in excess of 72 hours.
- Approximately 12% of drivers reported less than 4 hours of sleep on one or more working days in the week preceding the interview. These drivers are likely to be operating their vehicles while having a significant sleep debt.
- Approximately 20% of drivers who reported having less than 6 hours of sleep before starting their current journey reported 40% of the hazardous events

- Twelve percent of drivers who reported having had a crash in the previous 9 months identified fatigue as a contributing factor
- Five percent of the unregulated drivers reported having experienced a hazardous, fatigue related event, such as nodding off, on their current journey."
- 20% of drivers who reported having had less than 6 hours sleep reported 40% of the hazardous events."
- Many drivers and company representatives reported fatigue to be a problem for other drivers but considered themselves or their companies' drivers to be relatively unaffected by fatigue
- The authors concluded the paper by comparing their data on unregulated drivers' perceptions about fatigue to those reported by Williamson et al. (1992) for mainly regulated drivers. The results suggest that unregulated drivers perceive that fatigue is a problem for themselves less frequently than regulated drivers (10% versus 28-35%). Similarly, fewer unregulated drivers considered fatigue to be a general industry problem than did regulated drivers (39% versus 78%). These differences in frequency ratings may be due to differences in the attention paid to fatigue as a safety problem in regulated and unregulated states.

(III)3.2 Feyer, A.M., Williamson, A., Friswell, R. "Balancing work and rest to combat driver fatigue: An investigation of two-up driving in Australia." (1997). Accident Analysis & Prevention, 29 (4) 541-53.

Description of Study

This study was designed to examine the nature and impact of two-up driving operations on fatigue. Long-haul truck drivers were measured on a 4,500 km round trip. The driving operations of single driving (i.e., a solo driver) and two-up driving (i.e., pair of drivers operating a truck continuously, alternating work and rest) were compared.

A "between groups" design was used for this study, in which each participant only drove one evaluated trip using his regular operation –either two-up or single. Drivers were asked to drive a 4 to 5 day round trip of approximately 4500 km. in Western Australia. At the time of the study, the state of Western Australia did not have enforced driving hours regulations. Twenty-two of the 37 participants regularly worked two-up operations on the selected route and 15 regularly worked as single drivers. A variety of measures were used to assess drivers' fatigue and its effects such as heart activity, speed and steering wheel angles, auditory reaction time tasks, cognitive tests, and subjective measures of fatigue. Prior to starting their trip, participants were also asked to complete questionnaires about their general state of physical health, their lifestyle and their pattern of work/rest in week preceding study.

Relevant Findings

- "Irrespective of driver operation, fatigue increased for drivers on long-distance trips typical of remote zone driving."
- "Two-up drivers reported and showed evidence of greater fatigue than single drivers before the trip started and appeared to be more fatigued overall for most of the trip."

- "Over the homeward leg of the trip, two-up drivers reported no change in the level of fatigue, with fatigue having peaked at mid trip. For single drivers, in contrast, fatigue peaked at the end of the homeward leg, despite considerable recovery at mid trip."
- While overall the two-up group showed greater fatigue compared to single drivers, some ways of doing two-up (e.g., overnight stationary rest, shorter trip duration) were less fatiguing than single driving.
- Two-up drivers started the trip more fatigued and this "disadvantage remained for most of the trip"… "but was most marked over the first leg of the trip where fatigue for two-up drivers continued to worsen at a greater rate than for single drivers."
- "… where work practices kept the fatigue under control, such as on shorter two-up trips and two-up trips incorporating overnight stationary rest, breaks were more likely to be helpful. In contrast, where fatigue was allowed to build-up, such as on single trips and on very long two-up trips without stationary rest, breaks did not provide relief once fatigue had accumulated."

- Overnight stationary rest for two-up drivers at mid trip, was associated with dramatic reductions in fatigue levels after the break, and allowed these drivers to finish the trip with the lowest levels of fatigue of any group, including single drivers. Two-up drivers who had no stationary rest, but had the shortest trip duration of any group showed an overall increase in alertness over the homeward journey, finishing the trip at roughly pre-trip fatigue levels."

- Working hours regulations for long distance drivers are primarily based on limitations to periods of driving and rest within a trip, largely in isolation from overall scheduling patterns. In contrast, the current findings strongly suggest that effective management of fatigue involves considerations of the whole pattern and timing of work and rest

(III)3.2 Hakkanen, H. and Summala, H. (2000). "Driver sleepiness-related problems, health status, and prolonged driving among professional heavy-vehicle drivers." Transportation Human Factors, 2(2), 151-171.

Description of Study

This paper summarizes the results of a survey conducted with 567 Finnish professional drivers who responded to a questionnaire, out of 2,000 randomly-chosen drivers who were invited to take part. The drivers had 5 different work descriptions, and were part of a non-political organization promoting truck drivers' interests. The mailed questionnaires were completed anonymously. The main purpose of this survey study was to examine the relation between truck drivers' health and sleepiness-related problems while driving. In addition, factors most likely to predict increased driver sleepiness were identified. Furthermore, frequency of non-compliance with the driving-hours regulations (in terms of driving more than 10 hours) and drivers' comprehension regarding the suitability of the regulation were surveyed. In Finland, truck driving hours are subject to control by EC regulation No. 3820/85, according to which the maximum driving time is 10 hr and the resting time is 11 hours per each 24-hr period. Previous studies had indicated that all drivers do not follow the limits set by the regulation.

The questionnaires requested information on the drivers' preceding 3 months' work, possible sleepiness-related problems at work and their opinions about maximum permitted driving times. In addition, they were also given parts of the Basic Nordic Sleep Questionnaire and the Epworth Sleepiness Scale to estimate the "prevalence of suspected sleep apnea syndrome and to collect data of driver's sleep history." Drivers were also asked questions about their self-perceived general health status and the occurrence of any chronic illnesses.

Relevant Findings

- "The results of the study indicated that approximately one third of all the drivers drive generally more than 10 hr, which violates the EC regulation."
- "More than 70% of the drivers felt that the maximum permitted driving hours should be at least 11 hr per a 24- hr period".
- Nineteen per cent reported having dozed off at least twice while driving, and 8% reported a near-miss situation due to dozing off during the past 3 months.
- "Sleepiness-related problems while driving appeared across all driver groups (i.e., long haul, short haul, bus drivers, drivers transporting dangerous goods, drivers transporting wood), including drivers transporting dangerous goods and bus drivers, and were strongly related to prolonged driving, sleep deficit and drivers' health status. The effects of the latter factors were interactive and cumulative: Frequent sleepiness-related problems occurred in more than one half (52.3%) of the "drivers with the combination of prolonged driving, sleep deficit, and lowered self-perceived health."
- The 10% of drivers who were suspected to have sleep apnea syndrome (note: screening through questionnaires only) reported having experienced significantly more frequent sleepiness-related problems while driving although they did not report a significant increase in the frequency of sleepiness-related accidents.
- Less healthy drivers were both significantly older and tended to work longer hours and report greater sleep deficits and more problems with alertness and sleepiness while driving. These differences extended particularly to drivers reporting chronic illness in the last three years.
- The evidence for a cause-and-effect connection between a chronic illness and sleepiness-related problems while driving was somewhat mixed. While "the univariate comparison between those with an illness and others suggested a marked difference in sleepiness-related problems," the "logistic regression analysis showed that when other relevant factors were controlled (e.g., age, driving time) the effect of a chronic illness was no more significant whereas perceived health status better explained sleepiness-related problems while driving." The authors suggested that this result might be partly due to the fact that the discovered illnesses were rather heterogeneous. Increased odds of having more frequent difficulties in remaining alert if the driver self-perceived as having no more than a satisfactory health.
- When all the relevant factors were controlled, shift type and driving time were the only work-related variables that significantly predicted more frequent difficulties in remaining alert ($p<.05$ and $p<.05$, respectively). The odds of having experienced more frequent difficulties increased by a factor of 1.85 if the driver had been driving a

night or irregular shift and by 3.57 if the driver had been driving more than 17 hr (compared to fewer than 6 hr driving).

- The authors conclude that the results give unreserved support for regulating driving hours and increase concern of the connection between professional drivers' health status and sleepiness-related problems while driving.
- Drivers were more apt to have frequent difficulties remaining alert if they had been driving a night or irregular shift, or had been driving more than 17 hours.

(III)3.3 Morrow, P.C. and Crum, M.R. (2004) "Antecedents of fatigue, close calls, and crashes among commercial motor-vehicle drivers." Journal of Safety Research, 35 (1).

Description of Study

This paper summarizes the results of a survey of commercial motor vehicle drivers in 116 trucking firms. The purpose of the study was to identify factors (i.e., fatigue inducing and company safety management factors) relevant to the prediction of driving while fatigued, close calls due to fatigue, and actual crash involvement among CMV drivers engaged in intra- and interstate truck driving.

Thirty-two of the 116 firms in the study were top safety-performing firms, 53 from average firms and 31 from poor performing firms. Drivers were asked a number of questions about fatigue-inducing factors such workload, schedule regularity, difficulty finding rest places, adequacy of sleep, insufficient recovery, per cent of time loading/unloading. In addition, participants were asked about the perceived safety climate in their company. The authors formulated 11 perceived safety climate items (e.g., "Our Company makes driving safety a top priority") and asked drivers to record their level of agreement). Finally drivers were asked about their fatigue while driving (e.g., nodding off while driving, etc.,), as well as frequency of close calls and crashes.

The authors proposed three models to account for the variation in fatigue while driving, close calls due to fatigue, and crash involvement. Proposition 1 specified that fatigue-inducing factors would account for variation in these outcome measures. Proposition 2 specified that "company safety management practices should account for variation in the outcome measures, controlling for fatigue-inducing factors associated with truck driving work." Proposition 3 contended that "fatigue while driving accounts for variation in the frequency of close calls due to fatigue and crash involvement, after controlling for fatigue-inducing factors and company safety management practices."

Relevant Findings

- "Fatigue-inducing factors inherent in driving work and safety practices" (e.g., schedule regularity, difficulty finding a place to rest, adequacy of sleep when working, insufficient recovery, per cent of time loading/unloading, etc.,) "accounted for appreciable variation in driving fatigue (R squared =. 42) and close calls (R squared = .35), but not crash involvement." Self-report measures were used to assess fatigue (i.e., 3-item measure). Crash involvement was measured using the sum of two items: 1) reportable accidents (to the company) and 2) chargeable accidents that drivers had been involved with over the last 2 years.

- Approximately one-fifth of the drivers reported having one or more reportable accidents, and approximately 4% reported having chargeable accidents. The raw data was adjusted to account for exposure and expressed on a per 100,000 miles basis. Drivers with reportable accidents had between .32 and 6.41 crashes per 100,000 miles, while those reporting chargeable accidents had between .29 and 1.03 crashes per 100,000 miles. The measure exhibited a Cronbach alpha of .85.

- "Driving while fatigued accounted for incremental increases in the amount of variation in close calls, after consideration of inherent factors and safety practices."

- Safety practices (e.g., establishment of a strong safety culture, dispatcher scheduling practices, company assistance with fatiguing behaviors such as loading and unloading) have considerable potential to offset fatigue-inducing factors associated with truck driving work."

- While there is an assumption that employees will use off-duty time to engage in restorative activities, the insufficient recovery results reported in this study, led the authors to conclude that "drivers do not necessarily spend their non-work time in this manner". While drivers may not engage in job-related activities during their recovery periods, some drivers do engage in activities and sleep patterns that lead them to report back to work already fatigued. 47% of the drivers reported that they started the work week fatigue with some regularity. The authors note that the results "suggest that the potential misuse of off-duty time can be mitigated by the presence of a strong safety climate or enactment of policies targeted at fatigue-inducing activities (i.e., companies can act to reduce this problem)."

(III)3.4Williamson, A., Feyer, A., and Friswell, R. (1996). "The impact of work practices on fatigue in long distance truck drivers." Accident Analysis & Prevention, Vol. 28, No. 6, 709-71

Description of Study

The aim of this Australian study was to investigate the relationship between staged driving and fatigue. Professional truck drivers completed a 12 hour, 900 km trip under each of three driving regimes – a relay (staged) trip, a working-hours-regulated one-way (single) trip, and a one-way (flexible) trip with no working hours constraints. All of the observed trips took place overnight. The staged trip entailed driving from Sydney or Melbourne to the trip midpoint (Tarcutta), exchanging trucks or loads with a driver coming in the opposite direction, and then returning to the point of origin. "The single one-way trips involved driving directly from Sydney to Melbourne, and the flexible one-way trips involved driving from Melbourne to Sydney." "Under the regulations, drivers on single and staged trips were obliged to break for 30 minutes after each five hour period. Under the flexible regime drivers could choose to take breaks as often or as rarely as they needed with no constraint on the time taken to complete the trip." All of the observed trips took place overnight. Most trips began in the early evening and night between 16:00 and 23:59. The three driving regimes did not differ significantly in starting time. While, on average, the staged trips took longer to complete than flexible trips, the trip lengths differed by only 40 minutes. The study employed subjective (e.g., Stanford Sleepiness Scale, etc.), physiological (e.g., heart rate), and performance (e.g., speed, steering variability, reaction time, etc.) “measures to examine the relationship between the characteristics of staged driving and the development of fatigue.

Relevant Findings

- Although there was some evidence that fatigue developed differently within the three driving regimes (staged, single, and flexible), the levels of fatigue experienced by drivers increased markedly over all the trips

- Drivers tended to feel most fatigued on staged trips and least fatigued on single trips, however, this pattern was in evidence before driving commenced and post trip had not been modified by the intervening driving regime.
- “None of the regimes demonstrated any overall advantage in combating fatigue compared to the other regimes.”
- It is clear from the findings that “even relatively short 12-hour trips are tiring, and that effective strategies for fatigue reduction need to be identified.”
- The number of breaks taken increased across flexible, single and staged trips, suggesting an increasing need for rest as a function of driving regime. However, breaks were taken after similar periods of driving for the three trip types (Table 1). The longest driver period (4.5 hours) routinely occurred before the first break and the shortest drive period (2.5-3 hours) preceded the second break
- Pre-trip level of fatigue appears to be an important determinant of later fatigue. This raises questions about the ongoing work schedules under which long distance drivers operate, “and highlights the need to allow adequate rest and recuperation between trips and between blocks of trips to prevent chronic sleep loss and to reduce fatigue.”

(III)4 INSTRUMENTED AND/OR LABORATORY STUDIES OF DRIVER FATIGUE AND PERFORMANCE

(III)4.1 Baas, P.H. (Transport Engineering Research New Zealand (TERNZ)), Charlton, S., and Bastin, G. (2000) “Survey of New Zealand truck driver fatigue and fitness for duty.” 4th International Conference on Fatigue and Transportation, Fremantle, Western Australia.

Abstract

This study involved Interviews and simulator-based performance test conducted at depots, wharves, markets and other locations throughout the North Island of New Zealand throughout the day and night. The reported analysis covers results from the first 100 drivers.

The survey was conducted with 600 truck drivers at depots, markets, etc. around the North Island of New Zealand. Interviews focused on “driver demographic and work/rest patterns, drivers’ attitudes towards fatigue, propensity towards daytime sleepiness, and a self-assessment of the driver’s momentary level of fatigue.” A simulator-based performance test of driving was also undertaken on adapted version of the commercially available truck operator proficiency system (TOPS). “In the course of its development, TOPS passed through several verification and validation stages resulting in a pass/fail criterion for driver performance.” The performance test consisted of a standard driving task, a dual-axis sub-critical tracking task, and a tertiary or side-task requiring driver monitoring and periodic responses. "Calculation of pass/fail scores was based on five performance index coefficients (linear combinations of the performance variables). For each driver the five performance indices were calculated and compared to established performance criteria for each of the indices. The indices focused on the following five general categories: curvative error variability, divided attention response time variability, throttle activity variability, steering activity variability, longitudinal speed variability. A driver was required to obtain a passing score on each of the five performance indices to receive a passing score for the trial as a whole."

Relevant Findings:

- The drivers' typical workday length ranged from 6 to 15 hr with an average across all drivers of 11.89 h and a S.D. of 1.683.
- "The average number of days driving per week ranged from 3 (relief and part-time drivers) to 7, with an average of 5.35 days, standard deviation of 0.557 days."
- Drivers typically rated fatigue to be a problem for other drivers (21%) more often than for themselves (8%).
- A much lower proportion of drivers rated fatigue as "never" being a problem for them as did drivers in Hartley et al's study (13% as opposed to 35.5% in Hartley et al).
- 33% of drivers reported that they did not comply with the hours of service regulations (11 hours driving in one day) , and only 69% reported compliance with the requirement for minimum rest of 9 hours
- Drivers had an average of just one and a half meals per day (0.5 of a meal was defined as a light snack, usually while driving).
- The average Epworth Sleepiness Score of 7.53 (S.D. of 4.47) was substantially higher than the average score of 5.7 for truck drivers and 6.2 for automobile drivers reported in previous research (Maycock, 1995).
- 91% of all drivers passed all five of the performance criteria for the performance test on the simulator. "Of the 9% of drivers displaying driving performance below the criterion level, eight drivers failed the first performance criterion, a linear combination of measures predominantly associated with curvature error variability."
- "Of the drivers' activity and demographic measures, two were found to be particularly reliable predictors of simulator task performance: average distance driven per shift and driver age, $F(2, 98) = 8.42$, $P<0.01$. Drivers with an average daily route of fewer than 250 km and drivers 37 years and older were much more likely to fail the performance test." The authors noted that at this stage it was unclear "how to interpret the route length and age effects in the TOPS results"

(III)4.2 Balkin, T., Thome, D., Sing, H., Thomas, M., Redmond, D., Wesensten, N., Williams, J., Hall, S., and Belenky, G. (2000). "Effects of sleep schedules on commercial motor vehicle driver performance." Department of Transportation, Federal Motor Carrier Safety Administration.

FMCSA Tech Brief, 2000/09 (FMCSA-MCRT-00-015)
"Effects of sleep schedules on commercial motor vehicle driver performance – Part 2"

Note: These studies were the primary source used to form a relationship between PVT and truck crash risk, and also contributed to the relationships embedded in the SAFTE/FAST sleep and performance model.

Description of Study

The studies were conducted to gather and analyze data on commercial motor vehicle driver rest and recovery cycles, effects of partial sleep deprivation, and prediction of subsequent performance. The project was composed of two studies

Field Study:

Study involved actigraphic assessment of sleep and driver/sleep logs, conducted with long and short haul CMV drivers over 20 consecutive days. The drivers wore the Walter Reed wrist actigraphs at all times except when bathing or showering. In addition they completed sleep logs on driver's daily log sheets to gather subjective information about sleep times, sleep latency, arousals during sleep, alertness upon awakening, naps (number and duration), and self-reported caffeine, alcohol and drug use. The data from each actigraph were downloaded to a personal computer, and each 24-hour actigraph recording period was examined for sleep in its entirety regardless of the duty status type or length indicated on the daily log sheet.

Laboratory Study:

Primary objectives of the laboratory study were to "1) determine the effects of four sleep/wake schedules on alertness and performance, and 2) develop an algorithmic model to predict performance on the basis of prior sleep parameters." Drivers had 3 days of orientation and baseline sleep in the laboratory before data collection commenced over 7 days of performance testing with 3, 5, 7, or 9 hours of sleep each night. The recovery period, that followed, lasted 4 days with 8 hours in bed each night. A wide variety of measures were utilized. Measures consisted of the psychomotor vigilance task (PVT), the cognitive performance assessment battery, driving simulator tasks (e.g., lane tracking) as well as sleep latency, EMG and sleepiness ratings. In addition to these measures, a number of health measures were taken (e.g., tympanic temperature, heart rate, and blood pressure). Primary objectives of the laboratory study were to 1) determine the effects of four sleep/wake schedules on alertness and performance, and 2) develop an algorithmic model to predict performance on the basis of prior sleep parameters." In addition to psychomotor vigilance

Principal Findings

Field Study:

- Both long- and short-haul drivers averaged approximately 7.5 hours of sleep per night, which is within normal limits for adults. "However, the short-haul drivers tended to consolidate their daily sleep into a single, off-duty period, whereas long-haul drivers obtained approximately half of their daily sleep total as daytime naps and/or during sleeper-berth time."
- As long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleep-berth time), it appears that they spend a significant portion of the work shift in a state of partial sleep deprivation, until the opportunity to obtain on-duty recovery sleep presents itself.
- There was no off-duty duration that guaranteed adequate sleep for the long or short haul drivers. As drivers likely use a substantial portion of their off-duty time to attend to personal business, off-duty time must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off-duty periods.
- The bulk of the first (main) daily sleep bouts for short-haul drivers were initiated between 2000 and 0200 hours. Sleep bouts initiated at these times lasted longer (i.e., clustered between 6 and 10 hours) than sleep bouts initiated at other times of day. Several of the sleep bouts initiated between these times lasted longer than 12 hours.
- Similar to the short-haul drivers, the majority of long-haul drivers' first sleep bouts were initiated between 2200 and 0359 hours. However, long-haul drivers initiated their first sleep bouts more frequently during 0000 and 0359 hours. The duration of long-haul drivers' first sleep bouts clustered between 6 and 10 hours in duration. Sleep bouts exceeding 10 hours in duration were uncommon and none exceeded 12 hours. Some sleep bouts were initiated in the early and late afternoon hours (1200 to 1959) and, unlike short-haul drivers, almost half of the first sleep bouts initiated during this time frame were longer than 4 hours in duration.
- There were large day-to-day variations in total sleep time for drivers in both groups. Sleep times varied for some long and short-haul individuals by up to 11.2 hours across the 20 study days for the long and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules. Some individuals showed a pattern that suggested chronic sleep restriction with intermittent bouts of extended recovery sleep. The authors felt that this suggested that although work/rest schedules can be devised to help minimize CMV driver sleep debt, optimal enhancement of driver alertness and performance will require additional and imaginative approaches.

Lab Study:

- On average, subjects slept 2.9, 4.7, 6.3, and 7.9 hours for the 3, 5, 7, and 9-hour time in bed conditions respectively, and displayed dose-dependent performance impairment related to partial sleep loss. (As can be deduced from the above sleep times, as sleep restriction was more pronounced, sleep latency periods declined, resulting in greater sleep efficiency or proportionally more sleep in the available period.)

- Performance in the 3-hour sleep group typically declined below baseline within 2 to 3 days of sleep restriction.
- Performance in the 5-hour sleep group was consistently lower than performance in the 7- and 9-hour sleep groups.
- Performance in the 7- and 9-hour sleep groups was often indistinguishable and improved throughout the study. However, the authors did note that "even a relatively small reduction in average nighttime sleep duration (i.e., 6.3 hrs of sleep – the average amount of sleep obtained by the 7-hr group) resulted in measurably poorer performance – e.g., on the PVT. This decrement was maintained across the entire consecutive days of sleep restriction.
- Virtually no negative effects on performance were seen in the 9-hour sleep group.
- Sleep restriction effects were consistent. The degree to which "sleep restriction impaired performance was measure-specific". "Across tasks, speed and throughput were consistently affected". "In general, performance for the 3- and 5-hour sleep groups was below that of the 7- and 9-hour sleep groups." "Thus, restricting sleep resulted in dose-dependent performance impairment."
- All cognitive tasks were sensitive to differential sleep restriction.
- The PVT was the most sensitive measure. (It was also the performance measure which was the most resistant to changes in performance due to learning, an important issue when effects over many days are being examined.) Even the 7-hour group with 6.3 hours of sleep showed decreased performance using this measure across the 7 days.
- The majority of driving performance measures (e.g., increased lane-tracking variability increased driving speed, increased speed variability and increased running-off-road accidents) also showed dose-dependent and/or cumulative sleep restriction effects.
- Following chronic sleep restriction, the first 8 hours in bed (6.5 hours of sleep) was insufficient for restoration of performance on the PVT task.
- During the 4-day recovery phase (8 hours in bed each night), 5- and 7-hour sleep groups showed minimal or no recovery, remaining consistently below the 9-hour sleep group and below their own baseline levels for the PVT.
- The 3-hour sleep group showed some recovery for the PVT on the first day and more on subsequent days but also remained well below their own baseline and below the performance of the other groups.
- Subjects' recovery to baseline or near baseline levels of performance on the PVT often required a second or third night of recovery sleep.
- These data suggest that after sleep debt has occurred (3, 5, 7 hr time in bed) a single bout of 8 hours of night sleep leads to recovery but not full recovery. While further sleep is required for full recovery, the number of subsequent sleep periods to reach full recovery is unknown. For the 3 hour group, the data suggests that even 3 nights of normal sleep (8 hours spent in bed on each night) is not sufficient to restore performance to baseline levels (depending on the task). This suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration (i.e., more than 8 hours of normal-duration sleep). This is a unique finding and requires replication.

- In contrast to the findings concerning PVT performance, the accident rate went back to baseline after one recovery day for all groups. In addition, lane position variability was near, but not quite back to baseline for all but the 9-hour group.
- On recovery days lane position variability was slightly worse for the 9-hour group who, after being allowed 9 hours in bed each night during the work period, were restricted to 8 hours of sleep.

- "The extant level of daytime alertness and performance capacity is a function not only of an individual's circadian rhythm, time since the last sleep period, and duration of the last sleep period, but is also a function of his/her sleep history, extending back for at least several days."
- Following more severe sleep restriction (e.g., the 3-hr group), recovery of performance was not complete after 3 consecutive nights of recovery sleep …this suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration.

(III)4.3 Dingus, T., Neale, V., Garness, S., Hanowski, R., Keisler, A., Lee, S., Perez, M., Robinson, G., Belz, S., Casali, J., Pace-Schott, E., Stickgold, R., Hobson, J.A., The Impact of Sleeper Berth Usage on Driver Fatigue. FMCSA, FMCSA-RT-02-050, Washington, DC, November 2001.

Federal Motor Carrier Safety Administration. "Impact of sleeper berth usage on driver fatigue: Final Report." (2002). Report Number: FMCSA-RT-02-070

Klauer, S.G., Dingus, T.A., Neale, V.L. and Carroll, R.J. (2003) "The effects of fatigue on driver performance for single and team long-haul truck drivers." Driving Assessment 2003 – The Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Park City, Utah.

NB All quotes are from FMCSA summary.

Description of Studies

This report documents research that was conducted on sleeper berth usage. In addition to focus groups with long-haul operators a field study was conducted on sleeper berth usage for single and team drivers. The report outlines a number of factors, discovered in a series of 10 focus groups, which are important to successful sleeper berth usage for single and team drivers. Based on the results of the focus groups and an accompanying literature review, the researchers designed an on-road study with 56 drivers (47 male, 9 female; mean age=42.6 years) constituting 13 teams and 30 single drivers, to assess the effects of sleeper berth usage on sleep, driver error and critical incidents. In this study, long-haul truck drivers operated heavy trucks for a minimum of six continuous days, with the typical run being seven to 10 working days, on their regularly assigned route. Data collection systems were installed on the tractors used by the drivers to collect sleeper berth environmental data, driving performance information, video of the driver's face, and subjective alertness ratings and data from the Nightcap sleep system. Data (i.e., computer and video) were collected prior to and during critical incidents such as lane and steering deviations.

Relevant Findings

Focus Groups

- "Team versus single driving was identified as a very important factor for drivers relating to quality of sleep." Drivers either loved or hated team driving and discussed various issues relevant to their preference (e.g., trust, partner's driving ability, driving smoothly, etc.). Drivers also discussed various equipment issues with respect to comfortable sleeping arrangements (e.g., noise, air-ride vs. spring-ride trucks, etc.,)

Field Study: Team Driving vs. Single Driving

- Single drivers were involved in significantly more critical incidents than team drivers. They were involved in "four times the instances of "very/extremely drowsy" observer ratings than were team drivers, and were more likely to push themselves to drive on occasions when they were very tired."

- More than one-half of the most severe of the critical incidents were caused by four of the thirty single drivers. In contrast, team drivers were generally very successful at avoiding circumstances of extreme drowsiness, drove much less aggressively and made fewer errors than single drivers.

- The main effect for segment of day was significant ($p < 0.05$). Team drivers tended to exhibit critical incidents associated with extreme fatigue during the (morning and night hours (morning: 04:00 to 11:59; afternoon: 12:00 to 17:59, night: 22:00 to 03.59). Single drivers "tended to show fewer extreme fatigue-related critical incidents during the morning hours, with gradually more critical incidents being attributed to the very drowsy categories during the evening and nighttime hours". The authors note that single drivers "were exhibiting signs of extreme fatigue during all hours of the day while team drivers only showed signs of fatigue during the nighttime and morning hours."

- Overall, team drivers were able to better manage their fatigue and critical incident involvement than were single drivers. This may be because team drivers are more likely to effectively trade-off driving duties with their partner prior to becoming extremely fatigued. It is also possible that, in effect, drivers undergo a natural "screening" process. Focus group participants noted that team drivers must be trustworthy with regard to their driving ability and be considerate of their resting partner.

Field Study: Quality of Sleep

- A number of findings indicated that the quality and depth of sleep was worse (e.g., more sleep disturbances) on the road, particularly for team drivers. They found that while the vehicle was in motion, the noise and motion environment in the sleeper berth degraded the drivers' sleep.

Field Study: Hours of Service

- Based on a report by Wylie et al., (1996), there were relatively few instances (about 2.2 percent) of "extreme drowsiness," with most of these instances being experienced by single drivers, again with a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive."

- The authors note that it "appears that the combination of long driving times and multiple days provides the greatest concern, with several results pointing to the presence of cumulative fatigue." As a result they believe that the length of shifts in the later stages of a trip must also be considered. However, the authors point out that "critical incidents and/or driver errors did not increase directly with the hours beyond the regulation," and that "there was a substantial decrease in the rate of critical incidents during some of the more extreme violations." However, they do caution that this should not be interpreted to mean that hours of service should be expanded due to the following two reasons: "First, it may be possible that the drivers were making a point to driver more carefully and cautiously because they were operating outside of the regulation and did not want to get stopped by law enforcement officials. Alternatively, they may have only risked driving outside of the regulations because they felt alert and knew that they could continue to drive safely."

(III)4.4 Gillberg, M., Kecklund, G., and Akerstedt, T. (1996). "Sleepiness and performance of professional drivers in a truck simulator – comparisons between day and night driving." Journal of Sleep Research, 5, 12-15.

This paper summarizes a study comparing daytime and night-time performance of professional drivers on a simulated driving task. The authors noted that to their knowledge no studies had been conducted reporting on the effects of sleepiness on night driving performance in a dynamic truck simulator using professional drivers as subjects. The secondary purpose of the study was to test whether a nap, or a rest pause, would affect performance.

Nine professional drivers participated 4 times in a counterbalanced repeated measures design. "The conditions were day driving (DAYDRIVE), night driving (NIGHTDRIVE), night driving with a 30 minute rest (NIGHTREST), and night driving with a 30 minute nap (NIGHTNAP)." Time of day was not specified. "Each condition consisted of three consecutive 30-min periods." The 30-min duration of each period was an adaptation to the maximal continuous driving period allowed by the simulator software. "For the DAYDRIVE and NIGHTDRIVE all periods were spent driving while the second period was either a rest pause or a nap for the other two conditions." "Mean speed, standard deviation of speed and, standard deviation for lane position were recorded. Self ratings of sleepiness (e.g., Karolinska Sleepiness Scale) were obtained before and after each 30-min period. Reaction time tests and 10 minute standardized EEG/EOG recordings were obtained before and after each condition". EEG/EOG recordings were obtained before and after each condition. EEG/EOG were also recorded continuously during driving.

Relevant Findings

- The authors noted that despite the relatively short task (continuously driving for only 30 minutes at a time) statistically significant differences between day and night driving performance could be demonstrated. The effects on driving were small but significant: night driving was slower, with a higher variability of speed, and higher variability of lane position.
- Subjective and EEG/EOG sleepiness were clearly higher during the night conditions.
- Reaction time performance was not significantly affected by conditions.
- The authors noted that the task per se affected alertness, as indicated by the clear increase in subjective and electrophysiological sleepiness as well as in reaction times over the three periods even for the day driving condition.
- Neither the nap nor the rest pause had any effect. The authors note that a nap of the same duration during the day, on the other hand, has been shown to have clear positive effects. They felt that as sleep inertia tends to be more pronounced with the longer wake times that will precede night naps (Dinges, 1985), this might have obscured the possible positive effects of the nap in the present experiment. It is clear, however, that the nap did not have a negative effect which could have been the result if severe sleep inertia had occurred. The authors conclude that the most reasonable explanation to the lack of nap effect is that it was too short to counteract the low levels of alertness during the circadian trough after an extended time awake.

(III)4.5 Hanowski, R. J., Wierwille, W. W., Gellatly, A. W., Early, N., and Dingus, T. A. (2000). "Impact of local short haul operations on driver fatigue." Department of Transportation Federal Motor Carrier Safety Administration.

Description of Study

This paper summarizes the results of an on-road field study focusing on the fatigue experienced by local/short haul truck (L/SH) drivers (i.e., trips less than 100 miles from home base) on typical workdays, whose vehicles were instrumented with data collection equipment. Forty-two male L/SH drivers (mean age = 31) participated in the study. Drivers completed 2 weeks of Monday-Friday daytime driving on normal delivery routes that were within 100 miles of home. Their distribution of work consisted of driving (28%), loading/unloading (35%), other assignments (26%), waiting to unload (7%), eating (2%), resting (0.5%) and other activities (1.5%).

The authors used subjective, objective and physiological measures to assess fatigue, inattention and drowsiness. Subjective measures included self-report on levels of stress. Objective measures included the degree of eyelid closure. Physiological measures included indications of sleep quantity and quality as collected by wrist activity monitors. In addition the “black box” data collection equipment installed in the truck collected driver performance associated with “critical incidents” (i.e., near-crash events). Several small video cameras were used to monitor each truck driver and surrounding traffic situation, and sensors collected date from the vehicle’s instruments. The authors conducted analyses of videotape of the three-minute interval preceding the start of a critical incident. An incident was defined as a control movement exceeding a threshold based on driver or analyst input. Analysts recorded eye transitions and the proportion of time that the driver's eyes were closed/nearly closed, or off the road, during these three-minute intervals.

Relevant Findings

- Over the two-week period, there were 77 incidents (average 1.8 per driver) where the driver was judged to be at fault. Inattention was thought to be involved in 57 critical incidents, and fatigue a contributor to 28 critical incidents (i.e., 20.8% of incidents where the L/SH driver was judged to be at fault).
- The majority of the L/SH driver at fault critical incidents were caused by about one-quarter of the drivers: ten of the 42 drivers were involved in 86% of the incidents.
- The younger and less experienced drivers were significantly more likely to be involved in critical incidents and exhibited higher on the job drowsiness.
- "Drivers tended to be involved in fatigue-related incidents earlier in the workweek. There were no fatigue-related critical incidents after the fourth day of the workweek."
- The highest frequency of driver-at-fault incidents was between noon and 1 PM. The increase in incidents during these periods may be attributed to increased exposure.
- Drivers demonstrated, to a statistically significant level, signs of fatigue for a time period immediately preceding incident involvement where the L/SH driver was judged to be at fault.
- During the study, the drivers' mean sleep was 6.43 hours per night (sleep log) and 5.31 hours based on the Actiwatch (developed by Mini Mitter Co., Inc.).
- Data was divided into two groups where fatigue was apparent or not apparent. "To classify incidents into one of these two groups, threshold values for PERCLOS and OBSERV were set such that fatigued drivers were defined as having PERCLOS greater than or equal to 0/08, or an OBSERV value greater than or equal to 40. If an event did not meet one of these criteria, then the driver was deemed to be 'not fatigued.'" Drivers who showed evidence of fatigue and were involved in fatigue-related incidents had less sleep and of a poorer quality than drivers who did not show signs of fatigue. The drivers from the beverage company typically worked 10 to 11 hours per workday. The snack food drivers worked roughly 12 hours per workday. The majority of drivers worked five days per week.
- The self-reported amount of sleep and quality of sleep for the night before the incident were less when the driver was categorized as being fatigued. Drivers in the fatigue group had 5.33 hours of sleep compared to 6.13 hours in the non-fatigue group.
- "…much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job." The authors concluded that off-duty behavior was the "primary contributing factor in the level of fatigue that was demonstrated during the workday."
- Drivers in the fatigue group spent more hours driving during the day of the critical incident as compared to drivers in the no-fatigue group.

(III)4.6 O'Neill, T.R., Kruegar, G.P., Van Hemel, S.B., and McGowan, A.L. (1999). "Effects of operating practices on commercial driver alertness." Rep. No. FHWA-MC-99-140, Office of Motor Carrier and Highway Safety, Federal Highway Administration, Washington, D.C.

O'Neill, T.R., Krueger, G.P., Van Hemel, S.B., McGowan, A.L. and Rogers, W.C. (1999) "Effects of cargo loading and unloading on truck driver alertness." Transportation Research Record, 1686, pp. 42-48.

Rogers, W. (2000) "Effects of operating practices on commercial driver alertness." Proceeding of the Conference Traffic Safety on Two Continents held in Malmo, Sweden, September 20 – 22, 1999.

Tech Brief (1999) (FHWA-MCRT-99-008) "Effects of operating practices on commercial driver alertness."

Description of Study

This project consisted of focus groups, a driver survey and interviews with CMV drivers focused on the physical requirements (loading/unloading) across the industry. This was followed by a driving simulator study which investigated "fatigue-related related decline in driving performance resulting from loading and unloading cargo," "non-duty time (rest and recovery) required to reestablish baseline fitness for duty," and "driver performance under a sustained 14 hours on/10 hours off schedule. Researchers examined driver performance over a 15-day period." Ten male CMV drivers operated a "driving simulator in simulated long-haul runs for a period of 15 days, including occasional loading/unloading sessions and a relatively high frequency of simulated crash-likely events." Performance measures and measures of subjective drowsiness were collected. In addition, participants wore wrist activity monitors to assess the amount of sleep.

Drivers were held to a schedule of 14 hours on duty (12 hours driving plus scheduled breaks) followed by 10 hours off duty. The daily driving schedule ran from simulator engine start at 0700 to shutdown at 2100. Breaks were taken on the experimental schedule and not at the subject's discretion (30-minute break at 1000, a 45-minute lunch break at 1345, and a 30-minute break at 1730). During week one of driving, half of the drivers conducted simulated loading/unloading operations for three days and no loading/unloading operations in week 2. The remaining drivers did the reverse (i.e., loaded in week 2). On loading days, drivers performed two 90 minute loading/unloading sessions during the driving day, one in the morning, and one in the afternoon.

During driving days a Psychomotor Vigilance Task (PVT) was administered 3 times (0645, 1330, 2100). Subjective examination of video records of drivers during simulated operations were conducted for samples taken from periods during which parallel indicators showed evidence of good or poor performance. Multiple measures were employed to gauge recovery, including sleep patterns, sleep latency, subjective sleepiness, and the Psychomotor Vigilance Test (PVT). These measures were repeated regularly 4 times each day (0900, 1300, 1700, 2100) during the 58-hour rest and recovery period.

The effects of loading and unloading task were mixed. There was an initial improvement in alertness; however, this effect wore off as the day progressed and may have contributed to a decrease in overall performance after 12 to 14 h of duty." "Drivers recovered baseline performance within 24-hours of the end of a driving week and should be fit to resume duty after 36 hours." "A schedule of 14 hours on duty/10 hours off duty for a 5-day week did not appear to produce cumulative fatigue."

Relevant Findings

- There was a gradual decline in driver response quality over time (hours at the wheel). There were slight performance degradations in the mid-afternoon, but there were improvements after each break, whether for rest, meals, or loading activities. The authors did not discuss how long the improvement effect lasted.
- The rest breaks had an influence on critical safety measures. For example, the effects of 6.5 hours of driving were reduced to starting levels by the one hour lunch break for non-loading days. While the recovery effect of a rest break is not surprising, the magnitude of the effect is striking. (Note: As the loading/unloading variable contributed to a significant interaction it is of use to examine the days when no such activity occurred, since these are more typical of the industry as a whole, and are free of the loading/unloading variance).
- After the morning physical activity, there was an improvement in driver response to crash-likely simulated situations, probably due to a short-term invigorating effect associated with physical exercise and a break in driving routine.
- The afternoon loading/unloading session did not have the same effect on drivers. Driving performance deteriorated more rapidly after the afternoon physical activity, suggesting that cumulative physical/general fatigue and time-of-day effects are sufficient to overpower some short-term effects of a change in activity. Driving performance did return to starting levels near the end of the day.
- The ability to maintain speed within posted limits and gear shifting performance both deteriorated somewhat during the latter part of the driving day. The simultaneous occurrence of the two suggests deterioration in physical coordination and vigilance late in the day, but there was no consistent linear relation to hours of driving.
- The authors note that there is "no useful way to compare the cumulative effects of the 14/10 schedule with other possible schedules (including those logically subsumed, such as 10-hour and 12-hour duty periods) because the cumulative effects for each are confounded." However, what can be said about cumulative effects is that they "appear to be nil for practical measures (e.g., probe scores) and mild for parallel subjective measures such as subjective sleepiness." Duty-day subjective sleepiness, reaction time response, and measures of driving performance showed a slight but statistically significant deterioration over the driving week, but driver response in crash-likely situations did not show cumulative deterioration. The schedule of 14 hours on duty/10 hours off duty (12 hours driving) for a 5-day week did not appear to produce significant cumulative fatigue over the 2-week testing period.
- While there was an increase in measured sleep and a decrease in sleep latency on the first off-duty rest day following the end of the driving week, the authors do not believe that the peak sleep periods during the "weekend" days were due principally to sleep

deprivation. They noted that drivers varied in the number of hours of sleep per night, and a case-by-case examination of driver sleep patterns did not show a higher rebound for those who slept less during the driving week, indicating that the variation observed did not represent deprivation. They felt that the drivers did not appear to have accumulated significant sleep loss.

- Sleep latency was measured between 2200 and 2230 on the last driving day (Friday) of each week. At this point drivers were not ready to sleep, however tired they might feel, since they had just been released from a 14-hour driving day. The second sleep latency measurement was taken between 0900 and 0930 the next morning (Saturday), shortly after the drivers had awakened from a night's sleep. The third sleep latency measurement was taken at 1300 on Saturday and proved to be dramatically the shortest sleep latency.
- Drivers returned to baseline reaction time performance and alertness within 24 hours after the end of a driving week, as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. This effect was generally consistent across drivers. The typical recovery pattern involved extra sleep during the first rest day verified by wrist activity monitor, and an increased level of sleepiness during the afternoon of the first day (indicated by shorter sleep latency)

(III)4.7 Williamson, A., Feyer, A.M., Friswell, R., and Finlay-Brown, S. (2000) "Demonstration project for fatigue management programs in the road transport industry: Summary of findings."

Description of Study

The aim of this project was to evaluate work-rest schedules to begin to identify some model work-rest schedules to provide companies and drivers flexibility in meeting their operational needs and to manage fatigue most effectively. The paper is a summary of findings of the results of three different reports. As this paper a summary of findings, the paper does not include a great deal of detail. The first report describes the identification of three performance measures that have demonstrated sensitivity for detecting fatigue and its effects so that they can be used in developing models of work-rest schedules. The second and third reports focus on on-road and simulated evaluations of current and alternative work-rest schedules.

The first step in this project involved a comparison of performance on a "range of performance tests under conditions in which study participants should be tired, with performance under conditions in which they had been exposed to varying doses of alcohol" to identify measures that have demonstrated sensitivity for detecting fatigue. Performance tests were administered at regular intervals over time with increasing sleep deprivation (i.e., participants were kept awake a total of 28 hrs) and increasing blood alcohol levels (BAC) (four doses of alcohol to achieve increasing BAC). The authors could then identify which tests were sensitive to increasing alcohol doses and those which were sensitive to increasing sleep deprivation.

The second and third reports focused on four evaluations, consisting of two evaluations of the current working hours regulations in New Zealand, and two evaluations of alternative approaches to work-rest schedules. All the evaluations except one (a simulation) were conducted on-road using the performance measures developed in the first step of this project. Participants started the study after being on break for 24 hours to "obtain baseline information about performance when rested". Ratings of fatigue and performance were then taken at "strategic points across the work-rest schedule between two long 24 hour breaks." The alternative approaches to work-rest schedules were evaluated in a simulation study and an on-road study. The simulation study looked at the extension of the daily working hours limit from a "maximum of 14 hours in a 24 hour period to up to 16 hours in a 24 hour period. The overall schedule covered 60 hours. The longer hours were balanced by beginning and ending the schedule with a 6 hour break and having a mandatory 6 hour break at some point in the intervening 48 hours. Short breaks of at least 15 minutes were also required after every 3 hours of work. The evaluation was conducted as a simulation because it had not yet been authorized to be trialed on the road as part of the pilot FMP."

In contrast, the second evaluation of an alternative approach to work-rest schedules could be conducted on the road because "it was in operation as part of the pilot FMP." It "differed from the regulated hours regime by allowing for longer sustained periods of work at a stretch and splitting of the mandatory breaks between them. The regulated hours allow only five continuous hours of work before drivers take a break of at least 30 minutes. In this alternative schedule, drivers could work up to six continuous hours and only needed to take breaks in 15 minute periods, although they needed to take 30 minutes in total in every six hour period. The FMP also allowed drivers to divide the mandatory six hour continuous break into shorter sections. In all other ways, the work-rest schedule was the same as the regulated regime."

Relevant Findings

- While most of the tests showed deterioration in performance with increasing alcohol doses, not all the tests did so for increasing sleep deprivation.
- 0.05% BAC equivalence occurred at between 17 and 19 hours of sleep deprivation for most tests. This means that after around 17 hours of wakefulness, performance capacity was sufficiently impaired to be of concern for safety."
- There was little evidence that current working hours led to performance decreases large enough to "constitute a significant safety risk compared to alcohol equivalent levels at 0.05% BAC."
- In the simulation study of an alternative compliance approach, drivers were able to manage fatigue effectively over the first 16 hours of the schedule, however, their performance deteriorated significantly by the middle of the second 16 hour period. Performance at this time was "considerably poorer than the 0.05% BAC alcohol equivalence standard. It seems that the 6 hour break was insufficient to allow recovery and recuperation from the demands of the previous long day …" The work-rest schedule was "too demanding for drivers to manage fatigue effectively."
- The results of the road test evaluation of the second alternative compliance approach showed that "reaction speed showed a deterioration across the study to levels that were suggestive of an increased safety risk based on the 0.05% BAC equivalent standard for performance".

- Both evaluations showed, however, that performance capacity deteriorates and fatigue levels increase in relation to factors like increasing hours of work (especially night hours), short breaks and breaks that only allow short or poor quantity sleep). While fatigue and performance capacity seems to be maintained with safe limits under the regulated regime, these findings indicate that where drivers or companies take the work-rest schedules beyond the current limits, they are likely to be increasing the risk of performance decrements sufficient to compromise safety.

- Evaluation of the current working hours regime suggests that provided drivers are rested to begin with, one full cycle of the regulated regime does not produce fatigue or performance capacity decrements that of concern for safety. There is considerable evidence however that performance decrements increase significantly as the schedule becomes more demanding. This is a warning signal for the development of alternative approaches to ensure that schedules are designed that do not simply increase the demands on drivers. The evidence from both evaluations of alternative compliance schedules suggested that they increased the demands on drivers, but did not balance them sufficiently with rest in order to allow recuperation and recovery from accumulated fatigue."

- These results do not mean that the working hours regulatory regime is the only satisfactory approach to managing fatigue. The results show clearly that it is possible to increase trip length to 16 hours, say, and still maintain good performance levels. It is not possible, however, to continue to do 16 hour trips without a longer break than is usually allowed, even in the regulated regime."

(III)4.8 Wylie, C.D. "Driver drowsiness, length of prior principal sleep periods, and naps." (1998). Transportation Development Centre. Report No. TP 13237E

Wylie, C.D., Shultz, T., Miller, J.C., and Mitler, M.M. (1997) "Commercial motor vehicle driver rest periods and recovery of performance."

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. (1996) Commercial motor vehicle driver fatigue and alertness study." (Executive Summary & Technical Summary)

Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., and Wylie, C.D. (1997). "The sleep of long-haul truck drivers." New England Journal of Medicine, 337(11).

Freund, D. and Vespa, S. (1997) "U.S./Canada study of commercial motor vehicle driver fatigue and alertness". Proceedings of the XIIIth World Meeting of the International Road Federation, Toronto, Ontario. June 16 – 20, 1997.

Description of Study

This paper summarizes the results of an on-road study with 80 drivers in the U.S. and Canada. The goal of this study was to assess fatigue related to Canadian vs. U.S. driving schedules. Data (e.g., loss of alertness, performance, etc.) was collected on drivers for over a period of 16 weeks. Drivers drove one of four driving schedules. Time of day was the "strongest and most consistent factor influencing driver fatigue and alertness." In contrast "hours of driving (time-on-task) was not as strong or consistent predictor of observed fatigue." "There was some evidence of cumulative fatigue across days of driving."

The study used a between-subjects design involving four driving schedule conditions: C1- 10 hr daytime (5 consecutive days); C2-10 hr rotating (5 consecutive days, starting 3 hrs earlier each day); C3- 13-hr nighttime start (4 consecutive days); C4- 13-hr daytime start (4 consecutive days). 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." Various measures were taken: driving task performance (e.g., lane tracking, steering wheel movement), driving speed and distance monitoring, performance on surrogate tests (i.e., code substitution, critical tracking test, simple response vigilance test), continuous video monitoring, physiological measures as well as driver-supplied information (e.g., daily logs, Stanford Sleepiness Scale rating).

Relevant Findings

- Time of day was far more important than time-on-task or cumulative number of trips in predicting driver fatigue.
- Drivers in the C3-Nighttime condition had the least amount of sleep of all the conditions.
- Night driving (e.g., from midnight to dawn) was associated with worse performance on four important criteria" (e.g., average lane tracking standard deviation, etc.).
- "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."
- Drivers had approximately 2.5 hours of sleep than the amount of sleep they identified as their ideal.
- Drowsiness in Conditions C3Nighttime and C4Daystart was markedly greater during night driving.
- The observed prevalence of drowsiness formed a distinct peak about 8 hours wide, spanning late evening until dawn, and a 16-hour trough.
- There was probably greater drowsiness in Condition C2-10 rotating, trips 4 and 5, because the rotating schedule had caused these last trips, on average, to be driven through the night. Although disruption of circadian rhythms and cumulative fatigue probably contributed, time of day appeared to be a major factor.

(III)5 TRUCK CRASH RISKS AND COSTS

(III)5.1 ICF Consulting and Imperial College Centre for Transportation Studies "Cost-Benefit Analysis of Road Safety Improvements" Final Report submitted to the European Commission, Brussels, Belgium, June 2003

Description of Study

The European Commission (EC) was in the process of revising a number of road safety regulations primarily associated with the harmonization and enforcement of these laws through the 15 members European Union at the time. The cost-benefit study was performed to support this initiative by evaluating the benefits and corresponding costs of applying international best practices in enforcing laws relating to speeding, drunk driving seat belt use, and selected commercial vehicle safety regulations. The section of the study addressing the reformulation and enforcement of commercial vehicle hours of service and vehicle condition laws considered many of the same issues as those raised in the RIA analysis for FMCSA. Because the study relied mainly on European and other international sources, the information developed was largely independent of the sources used for this RIA analysis, and could provide another perspective on some key issues.

Relevant Findings:

- The fraction of truck involved fatal crashes where the truck driver was at fault in multi-vehicle was estimated at 17% by one source and 16% by another source, which also estimated that there was shared responsibility in another 14% of multi-vehicle crashes. In addition, the truck driver is at fault in the 20% of crashed that only involve a single vehicle. Taken together these results suggest the truck driver is at fault in about 36% of all truck-involved fatal crashes. In addition, one source suggested that the truck driver was at fault in a higher fraction of non-fatal crashes, up to 50%, but the data are probably less reliable.

- Of the crashes where the truck driver was at fault, the sources suggested that fatigue was a significant factor in 15-20% of all crashes, and up to 30% in fatal crashes. This leads to an estimate that fatigue is a significant factor in between 6 and 10% of all truck-involved crashes. Several sources make the observation that truck driver lifestyle off the job is a significant factor in fatigue-related crashes, and cannot be easily controlled by regulations or trucking firm managements.

- Several sources used showed that better safety management by trucking firms could have a substantial impact on crash rates, especially by raising the performance of the worst performing firms and drivers. The improvements extended beyond just HOS related crashes and could involve defensive driving techniques, better vehicle condition, better scheduling and improved pay and working conditions. Substantial reductions in crash risk, in the range 20 – 30% were cited is some example of applying such practices.

- Average per-crash costs for fatal and injury crashes were estimated at approximately 77,000 Euros, equivalent to $US 93,000. Given relatively higher medical and fatality costs applicable in the US, the corresponding cost under US conditions would be 50-100% higher.