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An Annotated Literature Review Relating to Proposed Revisions to the Hours-of-Service Regulation for Commercial Motor Vehicle Drivers

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An Annotated Literature Review Relating to Proposed Revisions to the Hours-of-Service Regulation for Commercial Motor Vehicle Drivers

Vehicle and Operations Division
Office of Research and Standards
Office of Motor Carrier Safety

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16. Abstract

The issue of duty time for drivers of commercial motor vehicles (CMVs) -- trucks over 4,536 kg (l0,000 lb) gross vehicle weight rating, passenger vehicles designed to transport more than 15 people including the driver, and vehicles of any size carrying hazardous materials in quantities requiring a placard under the U.S. Department of Transportation regulations -- has been an important part of the national safety debate since the late 1930s.

This report provides some of the extensive body of scientific research concerning hours of service, operator performance, and highway safety outcomes to those who have an interest or a stake in the Office of Motor Carrier Safety (OMCS's) development of new hours-of-service regulations. It consists of a synopsis of over 100 research studies and other documents that the OMCS obtained from researchers in the United States and overseas, including many that were provided by commenters to Departmental Docket OMCS-97-2350 and by members of a Scientific Expert Panel that provided consulting services to the Department during the summer of 1998. The abstracted research studies cover the following topics: contribution of operator fatigue to crashes; effects of sleep deprivation and countermeasures (naps) on alertness and performance; hours-of- service regulations (general considerations, driver working conditions, operational issues, regulatory compliance, schedules and shifts) and pilot tests and future opportunities (operational and performance models and technological approaches to driver alertness management).

All of the studies included in this review include synopses. Some were written by the authors of the studies and others by the reviewer. Many of the studies' synopses are followed by a short reviewer's commentary.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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Glossary

ANPRM	Advanced Notice of Proposed Ruling
ARAC	Aviation Rulemaking Advisory Committee
BAC	Blood Alcohol Concentration
BEDS	Bibliographic Electronic Databases of Sleep databases
CDS	Crashworthiness Data System
CMVs	Commercial Motor Vehicles
CVO	Commercial Vehicle Operations
CVES	Commercial Vehicle Enforcement Section
CVIU	Commercial Vehicle Investigation Unit
EEC	European Economic Commission
EEG	Electroencephalographic; Electroencephalogram
ERs	Electronic Recorder (for Hours of Service records)
FAA	Federal Aviation Administration
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMCSRs	Federal Motor Carrier Safety Regulations
GES	General Estimates System
GVWR	Gross Vehicle Weight Rating
HOS	Hours of Service
ICC	Interstate Commerce Commission
INRETS	Institut National de Researche sur les Transports et leur Securite
ITS	Intelligent Transportation Systems
IVHS	Intelligent Vehicle Highway Systems
JAMA	Journal of the American Medical Association
MCMIS	Motor Carrier Management Information System
MCSAP	Motor Carrier Safety Assistance Program
MSLT	Multiple Sleep Latency Test
NPRM	Notice of Proposed Rulemaking
NPTC	National Private Truck Council
NHTSA	National Highway Traffic Safety Administration
NPTC	National Private Truck Council
PARs	Police Accident Reports
PVT	Psychomotor Vigilance Task
REM	Rapid Eye Movement
SEM	Slow Eye Movement
SSS	Stanford Sleepiness Scale
SVRD	Single-Vehicle Roadway Departure
TC	Transport Canada
TFMS	Transitional Fatigue Management Scheme
TIUS	Truck Inventory and Use Survey
TRI	Trucking Research Institute
TRIS	Transportation Research Information Service
VMT	Vehicle Miles of Travel

An Annotated Literature Review Relating to Proposed Revisions to the Hours-of-Service Regulation for Commercial Motor Vehicle Drivers

Introduction

The issue of duty time for drivers of commercial motor vehicles (CMVs) – trucks over 4,536 kg (10,000 lb) gross vehicle weight rating, passenger vehicles designed to transport more than 15 people including the driver, and vehicles of any size carrying hazardous materials in quantities requiring a placard under the U.S. Department of Transportation regulations – has been an important part of the national safety debate since the late 1930s. The safety of these drivers, and of the drivers of those other vehicles who share public highways with them, has been a central topic in legislation, starting with the Motor Carrier Act of 1935, and continuing through the 1998 Transportation Equity Act for the 21st Century. Commercial motor vehicle safety, including the hours-of-service of CMV drivers who operate in interstate commerce, was regulated by the Interstate Commerce Commission (ICC) from 1935 to 1967 and was transferred to the newly-created U.S. Department of Transportation in 1968.

Scientific research has made important contributions to the development and assessment of regulatory proposals. An early empirical study of human fatigue and stress in a workplace environment was completed in 1941 under the direction of the U.S. Public Health Service to support the ICC's initial activity in hours-of-service regulations. However, the availability — and use — of scientific studies to the many stakeholders in the hours-of-service debate has been mixed at best. The legislative and regulatory histories show many examples of "common sense" proposals that are now seen as having had a scientific basis. One example was the ICC's original regulatory proposal. It would have limited CMV drivers to 12 hours of duty in a 15 hour period and required motor carriers to give them 9 consecutive hours off-duty —

a schedule that would have maintained the circadian rhythm regularity. The histories also give evidence of various proposals and regulatory changes that appear to have been compromises that inadvertently or purposely placed other issues ahead of sound science. One example of this was the ICC's 1962 change that limited the length of driving and on-duty periods between the mandated off-duty periods, rather than within a 24-hour period.

This report provides some of the extensive body of scientific research concerning hours-of-service, operator performance, and highway safety outcomes to those who have an interest or a stake in the OMCS's development of new hours-of-service regulations. It consists of a synopsis of over 100 research studies and other documents that the Office of Motor Carrier Safety (OMCS) has obtained from researchers in the United States and overseas, including many that were provided by commenters to Departmental Docket OMCS-99-2350 (formerly FHWA-97-2350) and by members of a Scientific Expert Panel that provided consulting services to the Department during the summer of 1998. The abstracted research studies cover the following topics: contribution of operator fatigue to crashes; effects of sleep deprivation and countermeasures (naps) on alertness and performance; hours-of-service regulations (general considerations, driver working conditions, operational issues, regulatory compliance, schedules and shifts) and pilot tests and future opportunities (operational and performance models and technological approaches to driver alertness management).

All of the studies included in this review include synopses. Some were written by the authors of the studies and others by the reviewer. Many of the synopses are followed by a short reviewer's commentary

NOTE: On October 9, 1999, the Secretary of Transportation rescinded the authority previously delegated to the Federal Highway Administrator to perform motor carrier functions and operations. This authority has been redelegated to the Director, Office of Motor Carrier Safety (OMCS), a new office within the Department of Transportation [64 FR 56270, October 19, 1999]. Reports and other documents published prior to October 9, 1999 continue to carry the FHWA identification.

Background

The proposed Hours of Service (HOS) regulations would establish five types of commercial motor vehicle (CMV) operations based on the characteristics of their operations. They are long distance operations, regional operations, split shift operations, home base operations, and workers primarily performing work other than driving. These five different types of operations have five different, but related, sets of HOS rules. The specific definitions of the five types of operations and related default rules are as follows:

Type 1: Long distance operations
Type 2 - Regional operations
Type 3 - Split shift operations
Type 4 - Home base operations
Type 5 - Operations where driving supports the primary work activity

There are several reasons for the OMCS to define multiple categories of CMV operations for the purposes of the safety regulations. First and foremost, the operational requirements are different. The OMCS bases the proposed categories for the five types of operations upon the following four differences.

1. The amount of driving performed
2. The regularity of drivers' work and rest schedules
3. The location where drivers take their off-duty period
4. The proportion of driving performed in a normal work shift
5. The degree of supervision and oversight the motor carrier exercises over the driver

The OMCS defines Type 1 operations drivers as those who are away from their home base more than three days at a time. Their primary task is driving, although they may well engage in other activities — in particular, loading and unloading cargo. Drivers of long-distance motorcoaches might also handle luggage and assist passengers. Type 1 drivers have the highest travel distance based exposure of all driver categories (usually over 160,000 km (100,000 miles) per year; team drivers may have twice this amount).

Type 1 drivers may have regular or irregular wake-sleep cycles, depending upon the requirements placed upon them by their employing motor carriers, their clients (if they are independent owner-operators), their personal preferences, or a combination of all three. Compared to drivers in the other types of operations, they may have the least regular wake and sleep cycles; their schedules may often require them to obtain at least some of their sleep during daytime off-duty periods. Type 1 drivers sleep away from their home base. Most of these drivers use sleeper berths, but some sleep in motels, company sleeping quarters, or other locations.

The OMCS defines Type 2 operations as similar to those of Type 1, with one significant exception. The main difference is that drivers in Type 2 operations are away from their home base three or fewer days at a time and thus may be able to take a larger proportion of sleep periods in a familiar home environment. A Type 2 driver has a moderately-high annual travel-distance-based exposure — 120,000 km (75,000 mi) to 160,000 km (100,000 mi).

Drivers in Type 3 operations also spend most of their on-duty time driving but their driving patterns are different from the Type 1 and Type 2 drivers. They are local (or home-based) drivers with more than one assigned driving period. These driving periods might be separated by several hours. A typical Type 3 driver might drive a commuter motorcoach between the hours of 5:30 a.m. and 9:00 a.m. and 3:30 p.m. to 7:00 p.m. During the hours between 9:00 a.m. and 3:30 p.m., the driver might be off-duty, perform non-driving duties for the motor carrier, or hold another job. The Type 3 driver is in a different category from the Types 4 and 5 drivers (described next) because driving is the main part of their job and they are on-duty more than 12 consecutive hours.

Drivers in Type 4 operations work in the geographic vicinity of their home base. They are generally on regular schedules but they are not on duty more than 12 consecutive hours from the time they report for work until the time they are released. Driving comprises a significant part of their work — more than one-third of their on-duty hours.

Drivers in Type 5 operations also work in the vicinity of their home-base. The classification was devised to cover CMV drivers whose duties do not center around driving but who operate these vehicles as a necessary part of their work assignments. The difference between a Type 4 and a Type 5 driver is the amount of driving performed during a workshift –

Type 5 drivers drive no more than five hours in a workday. Drivers in Type 5 operations might include utility workers such as electrical, water, natural gas, or communications lines specialists; environmental remediation specialists; oilfield service workers; and operators of mobile medical equipment providing community patient services. Drivers working in passenger for-hire operations are *not* Type 5 drivers because their primary duty is driving.

The main reasons for differentiating among types of operations is the potential for schedule-induced fatigue due to irregularity of sleep cycles and differences in the nature of work performed. Some tasks are more challenging than others from a physical standpoint, involving tasks such as loading or unloading cargo, or climbing ladders to check equipment on cargo tank vehicles. Others are more challenging from a cognitive standpoint — for example, city driving requires a high level of vigilance. Some activities may not involve a concurrent physical or cognitive challenge, such as waiting for space at a loading dock, but can still affect the driver's alertness later on due to residual stress effects or sleep loss.

Regularity of duty cycle, provision of off-duty time to obtain sufficient sleep

Many studies undertaken in laboratories and in transportation and other workplace settings point to detrimental effects on worker alertness and performance associated with irregular duty cycles and insufficient time available for sleep during the off-duty period between workshifts. These effects include increased subjective self-assessments of tiredness/fatigue, poorer driving performance, increased performance errors, and increased potential for crash involvement based upon potential and actual driving exposure.

Consecutive Hours Off-Duty. Several researchers have commented that the off-duty times required under the current regulations — a minimum of 8 consecutive hours — may not be long enough to provide CMV drivers with the opportunity to obtain the 7 to 8 hours of sleep medical experts generally consider the average requirement for an adult. They have also raised questions about the regulations allowing a work-rest cycle shorter than 24 hours, introducing an undesirable disruption to the circadian cycle.

In order to address the concerns of schedule regularity and the availability of off-duty time of sufficient duration for CMV drivers to obtain the amount of sleep recommended by scientific and medical experts, the OMCS proposes to revise the on-duty and off-duty time provisions of the Federal Motor Carrier Safety Regulations (FMCSRs). The OMCS proposes daily on-duty periods equal to or less than the on-duty times permitted under the current hours-of-service regulations. The proposed off-duty periods are equal to or greater than the minimum times required under the current regulations. The total of on-duty and off-duty periods are proposed to total 24 hours.

It is instructive to consider how the hours-of-service regulations were developed. When the Interstate Commerce Commission (ICC) promulgated the first regulations over 60 years ago, they focused primarily on the long-distance driver. In the 1930s, long-distance driving meant a maximum of 250 miles at a maximum speed of 40 miles per hour, with an average speed of 25 miles per hour (11 M.C.C. 203). The most common CMVs in use at that time were straight trucks. After World War II, tractor semi-trailer combination vehicles became the primary long-distance CMV.

The level of scientific knowledge concerning the role of sleep in human alertness was limited in the 1930s compared to what scientists know today. The research conducted under guidance of the United States Public Health Service for the ICC that was used to rationalize that era's final regulations did not address the amount of sleep the driver-subject obtained. Although the ICC stated it planned to reassess the regulations and their influence on CMV safety after they had been in effect for some period of time, no record exists that it did so.

Until 1962, the HOS regulations limited driving and on-duty time in a 24-hour period. Although the on-duty time limit of 15 hours and the 8-consecutive-hour off-duty period were set in 1941, it is quite possible the actual off-duty period may have been slightly longer to comply with that 24-hour clock period. Thus, the 1962 rule change that introduced the requirement for driving and on-duty periods to be separated by an 8-hour off-duty period may have had two unintended effects:

(1) It placed drivers on a schedule that was irregular from a circadian standpoint; and
(2) It may have decreased the actual off-duty time provided to them.

In the case of drivers in the categories comprising the proposed Type 3, 4, and 5 operations who generally return to their homes at the end of a workshift, 8 hours off-duty does not account for the time needed to commute to and from the job, eat meals, and take care of minimal personal needs. The following examples from the study performed by Wylie et al. (1996), the *Commercial Motor Vehicle Driver Fatigue and Alertness Study*, illustrate this. The drivers participating in that study operated under schedules set up to allow driving up to the maximum time periods allowed under their respective United States and Canadian regulations. The drivers returned to their regular work-reporting locations at the end of a shift. Drivers participating in the DFAS in the regular 10-hour daytime driving schedule spent 5.8 hours in bed and 5.4 hours asleep. Study drivers on a regular 13-hour daytime-start driving schedule spent 5.5 hours in bed and 5.1 hours asleep. The time-in-bed similarities between the 13-hour and 10-hour daytime drivers was likely due primarily to the proximity of the sleep center — the 13-hour drivers had to commute less than 10 minutes between their home terminal and the sleep laboratory. (All times cited are for the principal sleep periods and do not include the naps that some drivers took during their workshifts.) Also, the drivers in both of these daytime-driving groups were able to obtain their principal sleep during optimal times of the day, starting late in the evening and ending early in the morning.

The intent of providing a "consecutive sleep period" is to afford drivers a more favorable range of opportunities to obtain sleep to recuperate from the demands of a daily work period. The "additional off-duty" hours are set up to provide a degree of flexibility for drivers and motor carriers, allowing a longer single period of off-duty time or several shorter ones. This would provide flexibility for drivers to use a portion of this break time for taking naps if they desire. The need for breaks and naps is highly dependent upon the driver's situation from trip to trip and the proposal would not specify a time during the workshift when the "additional off-duty period" is taken. The benefit of naps has been documented by researchers in several operational settings. Although naps cannot substitute for a longer period of restorative sleep, they can certainly be used profitably, from a physiological standpoint, as a supplement to the principal sleep period.

The proposed duty period for the Type 4 operation home-based driver is identical to those of the "100 air-mile-radius driver" as described under section 395.1(e) of the Federal Motor Carrier Safety Regulations (FMCSRs). This provision allows drivers duty status records to be maintained using a timecard, rather than the more detailed record of duty status. It applies to CMV drivers who operate within a radius of 100 air-miles (185 km or 116 statute miles) of their normal work reporting location and who are released from work within 12 consecutive hours of the time they commence work. These drivers almost always work regular schedules and return to the location they are dispatched from at the end of each work period. In most cases, they operate within a limited geographic area and have some off-duty time during their workshifts.

The Type 5 operations driver operates a CMV for a limited amount of time during the workshift. (The driving time definition continues to be "all time at the controls of a commercial motor vehicle in operation." The amount of driving time has been set to be less than or equal to five hours for discussion purposes.) Because these drivers have limited amounts of driving time, they also have less exposure to other vehicles and the potential for crashes is lower. However, because the total proposed off-duty time is less than the time proposed for drivers in Types 1, 2, 3, and 4 operations, it will still be important to consider the scheduling of driving and off-duty times to minimize circadian-based decrements in performance.

Circadian Rhythms. It has been well established that the hours of the day and night are not equivalent from the standpoint of human alertness and safe, efficient, and productive performance of workplace tasks. At the same time, it is important to maintain access to and availability of motor freight and passenger transportation services for people and goods that must move during the night. The OMCS's Notice of Proposed Rulemaking (NPRM) addresses this in two ways. It proposes to provide off-duty time for drivers to take at their own option during the work period. It also proposes to require an extended period at the conclusion of a workweek to allow drivers to obtain restorative sleep between the hours of midnight and 6:00 a.m.

The OMCS had considered proposing to limit driving time between midnight and 6:00 a.m. to 18 hours per workweek. The basis for that was a recognition that it is far more difficult physiologically to obtain sound sleep during the day and that alertness and performance show definite degradation after several sleep periods that are less restorative due to poor quality and/or quantity. The limitation was also designed to offer operational flexibility. Some types of operations may require three consecutive periods of night driving; others may require driving on alternate nights, and still others might require driving during part of this period. However, an economic analysis determined that the net costs would exceed the net benefits of this option and the agency decided not to include it as a provision of the NPRM.

The NPRM would not propose differential alertness requirements for driving and non-driving activities. Very little research has been performed on the differential effects on alertness and cognitive performance of driving and non-driving activities. Most research of this nature has focused on a worker's ability to sustain long periods of physical activity — and performance of this type of work, in contrast to tasks that require high levels of vigilance and cognitive performance — appears to be less sensitive to effects of sleep deprivation. This could be a concern for the drivers in some Type 5 operations who could be required to drive after a long workshift. However, this concern is mitigated somewhat by the lower proportion of driving proposed to be allowed during a workshift and the requirement for the duty and non-duty cycles to total 24 hours.

Time-on-Task. The FMCSRs currently prohibit driving of a CMV after the driver has accumulated 15 hours on-duty. All of the proposed operational categories would limit on-duty time to 12 hours or less in a 24-hour day. In no case would drivers be permitted to drive more than 12 hours in a 24-hour day.

The longest driving period that has been studied, that the author is aware of, is the 13-hour driving period allowed under the Canadian National Safety Code. This limit was not based on a research-based justification. Part of the reason it was selected was because it is the driving time between Montreal and Toronto, a major transportation corridor. In Australia, up to 14 hours of "continuous active work" that is driving and non-driving activities in a 24-hour period are allowed under the recently-formulated Australian National Road Transport Commission's Transitional Fatigue Management Scheme (TFMS). Team drivers are limited to 12 continuous driving hours. The TFMS allows motor carriers and their drivers additional flexibility in conducting their operations but does not permit them to reduce the regulated minimum 10-hour daily rest period (6 hours of which must be consecutive) nor to exceed the regulatory maximum cumulative working limits (72 hours in 7 days). It also requires that motor carriers who wish to be registered as TFMS employers make a formal application with the appropriate road transportation agency, provide extensive training for drivers and scheduling personnel, and commit to documenting and managing CMV driver fatigue. We are not aware of research used to justify the length of the continuous driving period. Western Australia and Northern Territories do not currently have prescriptive hours-of-service regulations; motor carriers are subject to "Duty of Care" legislation under the Occupational Health and Safety Act.

Although Wylie et al. (1996) did not find differences in the prevalence of drowsiness in video data between the 10-hour regular-schedule (daytime) drivers and the 13-hour day start drivers, we must stress that this comparison could not be performed for nighttime drivers because the study design did not provide for it. A simple mathematical model of rhythmic (circadian) effects seen in the video-drowsiness data was not improved with the inclusion of elapsed time since trip start nor cumulative number of trips made. However, in another correlation of a broader set of data elements, the elapsed time since start of trip was considered important because of its strong relationship to driver self-reports of their level of alertness, even though the self-reports differed sharply from objective measurements. The researchers hypothesized that these self-reports indicated increasing stress or compensatory effort and the drivers had diminished motivation and ability to remain alert by the end of their trips.

Long duty days can lead to loss-of-alertness through effects of time on task. For these drivers, the time afforded should provide the flexibility to permit them breaks for meals, rest, and naps. Although the effects of breaks taken without a meal or a nap may have a limited effect on objective measures of alertness and performance, many researchers have shown improvements in workers' subjective assessments of their alertness, outlook, and mood. We cannot afford to ignore these subjective assessments — how we "think" we feel can influence how we actually perform. In the case of breaks where naps were taken, research studies show definite improvements in alertness and performance.

However, some advocates of increasing driving and duty hours have misinterpreted these statements, contending time-on-task is not a factor influencing driver alertness and safe driving performance. Although time-of-day was a more reliable factor as far as the video observations and objective performance measures were concerned, the ability of humans to maintain the levels of vigilance and cognitive performance required for safe driving, or their belief that they can maintain their performance level, is clearly influenced by the time spent performing the task.

Numerous studies have documented performance and alertness decrements after periods of driving far shorter than 13 or even 10 hours. Several studies have indicated decrements after 7 to 8 hours. However, not all of the studies differentiated between time-of-day and time-on-task effects, nor did they control or observe how the drivers spent their off-duty time. This makes a blanket assessment difficult. In addition, many of the studies did not or were not able to accurately document, control, or assess participants' sleep quantity or quality. This is another area where it is difficult to directly apply research results to the task at hand. However, the studies that clearly documented changes in alertness and performance as a function of time-of-day provide a much clearer picture.

Before we leave the subject of time-on-task and driving, we must note several States with the highest numbers of fatal-outcome CMV crashes — California, Florida, and Texas. These states also have the longest driving hours permitted under the OMCS's Motor Carrier Safety Assistance Program (MCSAP) tolerance guidelines (described in Appendix C to 49 CFR Part 350). We describe three studies of certain classes of CMV drivers exempted from various provisions of the hours-of-service regulations later in this document.

The converse of long duty hours is a shorter period of time remaining for the off-duty period if we wish to develop hours of service regulations allowing a driver to adhere to a 24-hour wake-sleep cycle. As several researchers point out, there is a dual predicament with night workers: not only are they required to perform tasks during the time of day they are least able to from physiological and cognitive standpoints, they must sleep during the time of day they are least receptive to it. Wylie et al. (1996) noted *A statistically significant negative correlation was observed between sleep length and drowsiness, but there was no observational condition in which all drivers obtained adequate sleep and performed night driving, so there is insufficient data from this study to estimate 'normal' levels of nighttime drowsiness.*

Research studies synopses

The remainder of this document provides synopses of 110 reports, papers, studies, and other documents the OMCS believes are relevant to the development of improved hours-of-service regulations. The OMCS thanks those who provided comments to the Advance Notice of Proposed Rulemaking (ANPRM) docket as well as those who recommended the agency review and consider specific studies. We believe the studies previously summarized in the ANPRM as well as those summarized in this document reflect the results of a comprehensive review. However, the broad and dynamic nature of the many fields of research — surface vehicle crash investigation and analysis, sleep physiology, shiftwork scheduling, and operator performance under various work conditions — make it impossible for any literature review to be all-inclusive. A number of studies sponsored and co-sponsored by the OMCS are in progress and have not yet generated reports: summaries of the study objectives may be viewed at the World Wide Web site *http:/www.mcs.dot.gov;* search term "R & T."

Many of the synopses and discussions in this literature review include the term "fatigue." We must insert a word of caution on the use of this term. In the past, the term "fatigue" has been used as a shorthand phrase. Its use has become commonplace. But it is more complex than the states of sleepiness, drowsiness, and low-alertness that are central to our concern here. The eminent British human-factors researcher Ivan Brown defines "fatigue" as the decreased capability of doing physical or mental work, or the subjective state in which one can no longer perform a task effectively. No scientist can measure "fatigue." What they can and do measure and quantify is how alert a person is, according to how the person performs on tasks requiring sustained attention, hand-eye coordination, and responding to changes in their environment. They can also measure changes in how the body functions — changes in brain wave patterns, changes in eyelid position, changes in head position, just to name a few — that relate to how alert or how drowsy a person is. For these reasons, we prefer to use the more precise terms of "alertness" and "drowsiness." We believe these terms are a more accurate descriptor of the problem.[1] However, we have retained the terminology used in the cited studies.

The documents are arranged according to the following topics:

Contribution of Operator Fatigue to Vehicle Crashes.

Contribution of CMV Driver Fatigue to CMV Crashes.

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Technological Approaches to CMV Driver Alertness Management

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[1] *Statement of George L. Reagle, then Associate Administrator for Motor Carriers, Federal Highway Administration before the Senate Committee on Commerce, Science, and Transportation and Merchant Marine: Hearing on Driver Fatigue, September 16, 1998.*

Contribution of Operator Fatigue to Crashes

The issue of operator fatigue as a crash risk factor has been fraught with controversy. The widely-quoted National Highway Traffic Safety Administration (NHTSA) studies cite a figure based on assessments of Fatality Analysis Reporting System (FARS) data indicating 3.6 percent of CMV-involved crashes with fatal outcomes were cited as involving drowsiness/fatigue. However, other studies have provided widely varying estimates, ranging from around 10 percent to 40 percent. (See Wylie et al. (1996), pp. 2-1 to 2-4). None of the studies are directly comparable. The crash populations, crash outcomes, selection methodologies, assessment methods to identify whether or not fatigue was a causal factor, the types of vehicles involved, and the types of roadways involved are very different from study to study.

However, several of the NHTSA and NHTSA-sponsored studies also noted the role of fatigue in crashes involving recognition errors, such as daydreaming or distraction, dozing, or looked-but-did-not-see, is currently unknown. It is important to note that a far higher proportion of crashes cite recognition errors than driver fatigue. Some police crash reporting forms do not contain a check-off block for driver fatigue or drowsiness — if the driver is not coded as "asleep," no alternative classification to indicate a lesser degree of drowsiness is available to the enforcement official.

Brown, I.D., Driver Fatigue. (1994) ***Human Factors 36*****(2) pp. 298-314.**

This paper provides a broad overview of the issue of driving fatigue and the many potential factors that contribute to it, especially as they relate to professional heavy goods vehicle [truck] drivers .

Brown begins by exploring a historical distinction that some researchers (Bartley and Chute, 1947) drew between what they termed "psychological fatigue" and "physiological impairment." Although they noted that physiological impairment (related to performance of physically-demanding tasks) and psychological fatigue (subjectively experienced) were not necessarily experienced simultaneously, they did point to a situationally-experienced phenomenon. As Brown notes *"The personal nature of fatigue is emphasized by the finding* *that it can result from conflict. For example, fatigue can occur when an individual cannot meet self-imposed or externally imposed performance goals but is forced to continue working under adverse conditions by a sense of duty and/or the need to safeguard the lives of others." (p. 299).* He sums up this portion of the discussion with a viewpoint that fatigue as a feedback mechanism – an individual wouldseek to recover from stress and avoid further stress, but if forced to continue to perform tasks performance will eventually break down.

The next portion of Brown's paper explores the contribution of work-related factors to fatigue in workplaces in general: duty periods and cumulative duty limits, rest breaks and sleep periods, and circadian influences on work performance and the ability to obtain restorative sleep. Turning to driver fatigue in a general sense, Brown notes the emphasis on developing a time-on-task relationship: *"Researchers have frequently attempted to develop a reliable measure . . . and they have ignored the other contributory factors in real-life prolonged driving task."* (p. 306). He points our several studies that support drivers' self-regulating of their attention to the driving environment which he views as an adaption to their *"perceived changes in perceptual ability. Only when this self-regulatory process breaks down will prolonged driving become hazardous . . ."* (p. 307) and notes that this may be more likely to occur on a lightly-traveled highway or during the circadian nadir.

The final part of the paper presents Brown's reviews as a series of truck driver fatigue research studies from the late 1970's to the early 1990's. He points to factors such as the inability of many drivers to set the pace of their tasks, their irregular schedules, cab environmental stressors, and physiological factors such as driver age and sleep disorders as potential contributors to fatigue-related accidents. Among his conclusions:

- Official accident statistics do not reliably reflect the number of accidents related to driver fatigue.
- Time on task appears to have a limited effect on accidents for regular daily work periods less than 11 hours, but may have a more profound impact if the work periods are over 12 hours.
- Time of day (circadian rhythms) has a significant influence on accident risk.
- Sleep loss and sleep disturbance heighten the effects of fatigue on driving.

- European regulations [i.e., Circa 1993] do not adequately protect drivers from fatigue because they do not account for circadian effects on commencement or conclusion of driving time nor on the amount of time a driver has been awake.

Brown states that *The main effect of fatigue is a progressive withdrawal of attention from road and traffic demands* (p. 311). He offers a perspective concerning three different inattention states in a fatigued driver: eye closure from sleepiness, subconscious redirection of attention toward inner thought processes, and visual scanning of the traffic environment that is based on an expectation of unchanging task demands rather than current and dynamic demands. He terms this last concept "driving without awareness."

Reviewer's Notes: This paper was one of several in a special issue of the journal *Human Factors* that focused on fatigue. Brown explores several important questions relating to the physiological and psychological definitional aspects of fatigue and the contributions of time on task, circadian state, and adequacy (or, more properly, inadequacy) of sleep. Finally, he explores the documentation of fatigue as a causal factor in accidents and describes changes in the level of conscious attention paid to the task of driving.

Shelton, T. (1988). ***A Summary of Fatal and Nonfatal Crashes Involving Medium and Heavy Trucks in 1988.*** **(Report No. DOT HS 807 609) Washington, DC: National Highway Traffic Safety Administration.**

This report provides a summary of statistics on the crash experience of medium and heavy trucks with gross vehicle weight ratings over 10,000 pounds. Crash data sources were the National Highway Traffic Safety Administration's Fatal Accident Reporting System (FARS) and National Accident Sampling System General Estimates System (GES) and the Federal Highway Administration's Motor Carrier Management Information System (MCMIS). [The regulations concerning reporting of commercial motor vehicle accidents to the FHWA were changed in 1992. This information is now obtained from States rather than from the motor carriers whose vehicles were involved.]

Table 7 (p. 20) of the report indicates two percent of truck drivers involved in fatal crashes and one percent of truck drivers in injury crashes were coded as drowsy, sleepy, asleep, or fatigued. However, the Executive Summary of the report notes that *Truck drivers* *involved in fatal and injury crashes are rarely reported by police as being impaired by drugs, fatigue, or alcohol.* (p. i).

Summala, H. & Mikkola, T. (1994). Fatal Accidents among Car and Truck Drivers: Effects of Fatigue, Age, and Alcohol Consumption. ***Human Factors 36*** **(2) pp. 315-326. (Docket FHWA-97-2350, entry number 521)**

The authors collected data from in-depth studies on 586 single-vehicle and 1357 multiple-vehicle crashes in Finland in which at least one vehicle occupant died. The accidents took place in 1984-1989. In Finland, nearly all accidents with a fatality are reported to police. More than 90 percent of them are assessed by multidisciplinary teams that include police, road and vehicle engineers, a physician, and a psychologist.

The authors note that *Special care should be taken in the assessment of driver fatigue . . . [it] often must be inferred from less direct evidence.* (p. 317) They stated that their assessments were based on interviews with surviving drivers who may or may not have admitted to falling asleep or having been drowsy as well as interviews with passengers and others with less-direct knowledge of the driver's condition.

The authors found differences were found between trucks with and without trailers — the latter are driven mostly in the daytime, on short trips, distributing goods, while long-distance heavy-goods transport is often done at night. They found that the 15 tractor-trailer drivers who either fell asleep or whose fatigue was considered to have contributed to the crash were somewhat younger than other crash-involved drivers.

The authors' assessment of "time-on-task" contribution to the accidents indicated that 20 percent of truck drivers at-fault had been driving at least 10 hours before the crash, compared with 8 percent of the not-at-fault truck drivers. However, their assessment concerning "time elapsed since awakening" showed no differences between at-fault and not-at-fault drivers. However, no data was available on normal sleeping times or any estimate of cumulative fatigue over multiple days.

Horne, J.A. and Reyner, L.A. (1995). Sleep Related Vehicle Accidents. *British Medical Journal. 310*, 565-567.

The authors studied vehicle crashes where police were summoned during three 1-month periods in the years 1991-1994. The crashes occurred on major roads in southwest England and midland motorways. They gathered data from police databases for one study subset, and used on-the-spot interviews for the other.

The authors set up criteria to eliminate specific contributing crash factors such as alcohol, mechanical defects, speed, and poor weather. They also focused upon the crash type, including run-off-road and rear-end into the vehicle ahead, an absence of signs of brake application, the *police officer suspected sleepiness as prime cause*, and an assumption that *for several seconds immediately before the accident the driver could have seen clearly the point of run off or the vehicle hit.*

The authors determined that 16 percent of the crashes on major roads and over 20 percent on motorways in their study area to which police were summoned were sleep-related. They noted three major peak time periods: 2:00 a.m., 6:00 a.m., 4:00 p.m. About half of the drivers were men under age 30 and very few of the crashes involved women.

Reviewer's Notes. The reviewer believes several limitations that can affect the direct application of the study results to the issue of the contribution of operator fatigue to crashes. The researchers considered crashes involving all types of vehicles — passenger cars and trucks of all kinds — and considered high-speed roadways only. There is also a possibility that some of the police officers were responding to their recent orientation/training on the contribution of driver fatigue to crashes. They noted some crashes as fatigue-related that might have been caused by a driver's non-observation or recognition of a situation ("looked-but-did-not-see") or driver inattention — a response to their recent orientation/training.

Wang, J-S. & Knipling, R.R. (1994). *Single-Vehicle Roadway Departure Crashes: Problem Size Assessment and Statistical Description.* (Report Number DOT HS 808 113). Washington, DC: National Highway Traffic Safety Administration.

This report provides a problem size assessment and statistical descriptions for single-vehicle roadway departure (SVRD) crashes. The authors state "*SVRD crashes are major "target* *crashes" of various conventional and high-technology Intelligent Vehicle Highway Systems (IVHS) crash avoidance countermeasures. Indeed, more fatalities are associated with SVRD crashes than any other crash type."* (p. 1-1).

Data sources used were from 1991 FARS and GES. SVRD crashes amounted to 20.1 percent of the passenger car crash total; 13.5 percent of the combination-unit truck crashes; 12.4 percent of the single-unit truck crashes; and 18.2 percent of motorcycle crashes.

The authors found that for the SVRD-crash drivers where their physical condition had been coded, 4.4 percent were coded as drowsy or sleepy. The percentage for combination-unit truck drivers was somewhat higher (6.2 percent) than that for passenger vehicle drivers (4.5 percent). Drowsiness was coded more frequently in fatal SVRD crashes: 15.2 percent for combination-unit trucks and 7.3 percent for passenger vehicles.

Knipling, R., & Wang, J-S. (November 1994). ***Crashes and Fatalities Related to Driver Drowsiness/Fatigue.*** **Research Note. Washington, DC: National Highway Traffic Safety Administration.**

This report used the NHTSA FARS and GES field for 1989-1993 as the data sources for this review of statistics on crashes involving driver fatigue, drowsiness, or "asleep-at-the-wheel" conditions.

The authors assessment of GES data resulted in an estimate of 56,000 crashes per year (approximately 1 percent of 6.3 million police-reported crashes annually) where driver drowsiness/fatigue was cited in the police accident report (PAR). They state this estimate may be regarded as conservative because of the difference in reporting this driver condition on the PAR, the lack of evidence available to police to support reporting this factor, or inaccurate driver self-reports. The authors provide additional caveats: fewer than half of the crashes are reported to police, most drowsy-driver crashes are single-vehicle crashes, and drivers have little incentive to report a single-vehicle crash not resulting in serious bodily injury or property damage. Drowsiness was computed to be associated with 3.6 percent of fatal crashes and fatalities between 1989 and 1993.

The authors compare actual and potential involvements of drivers of passenger vehicles and of combination-unit trucks. Although combination-unit trucks were computed to have a lower exposure rate per vehicle-miles traveled than passenger cars (0.82 percent of truck crash involvements compared to 0.52 percent for passenger car involvements), combination unit trucks travel an average of 60,000 miles per year while passenger cars travel an average of 11,000. The life-cycle of trucks is longer than passenger cars, and the expected number of target drowsy-driver crash involvements in the life cycle of a truck is approximately 4.5 times greater than that of a car.

The authors also cited several other studies of drowsy-driver crash problem size. These included the Indiana Tri-Level Study: 2.1 percent of 420 cases cited "critical driver non-performance;" 56 percent involved "recognition errors;" Najm et al. (1994): (3.7 percent of CDS and GES cases identified as being caused primarily by driver drowsiness); Deering (1994): 1 percent "dozing;" 17 percent "daydreaming" and "distraction;" Hendricks et al. (1994): 6.9 percent SVRD crashes "driver fell asleep," extrapolated to 2.8 percent of all crashes; Harris and Mackie (1972); AAA Foundation (1985); NTSB (1990), and others.

Knipling, R.R. & Wang, J-S. (1995). Revised Estimates of the U.S. Drowsy Driver Crash Problem Size Based on General Estimates System Case Reviews. *Proceedings, 39th Annual Meeting, Association for the Advancement of Automotive Medicine.*

The authors revised an earlier estimate of drowsy-driver crashes after publication of a study of driver fatigue crash problem size assessment in New South Wales, Australia by Fell et al. They cited Fell et al. use of two criteria for classification: driver drowsiness cited on the police accident report, and pre-crash maneuver " 'suggeste[d] loss of concentration by the controller [driver] due to fatigue.' " Knipling and Wang noted that Fell's estimates of crashes in New South Wales in 1992 involving driver fatigue (6 percent of all crashes, 15 percent of fatal crashes, and 30 percent of rural fatal crashes) contrasted sharply with American (NHTSA) statistics that cited driver fatigue as a causal factor in 0.9 percent of highway vehicle crashes in the United States.

Knipling and Wang applied a definition based on conditions/crash trajectory to GES (General Estimates System) crashes identified based upon the drift-out-of-lane maneuver classically associated with drowsy-driver crashes. They statistically compared crashes where drowsiness was cited on the PAR and crashes where it was not.

The new analyses *indicated that drowsiness/fatigue is a discernible causal factor in 1.2 to 1.6 percent of Police Accident Reports as compared to the baseline GES estimate of 0.9 percent.* (Authors' Abstract).

Reviewer's Notes: These analyses confined the crash topology of interest to drift-out-of-lane. Other crash types associated with drowsy driving, such as head-on rear-end/lead vehicle stopped, were not considered. As fewer than half of all crashes are reported to law enforcement agencies, and this fraction increases significantly for property-damage-only crashes and crashes involving slight and (possibly) moderate injury, the estimate is still believed to underestimate the contributory role of drowsiness and fatigue in crashes. Furthermore, the GES estimate data set is composed mainly of passenger car crashes. It should not be used as a surrogate estimate for CMV crashes because of the differences in the drivers (professional v. non-professional), roadways driven, and differential exposures of the two groups.

Lyznicki, J. M., Doege, T.C., Davis, R.M., &Williams, M.A. for the Council on Scientific Affairs, American Medical Association (1998). Sleepiness, Driving, and Motor Vehicle Crashes. *Journal of the American Medical Association 279*(23): 1908-13.

The following is taken from the Abstract for this article posed on the JAMA WWW site.

OBJECTIVE: To assess the contribution of driver sleepiness to highway crashes and review recent recommendations to change federal hours-of- service regulations for commercial motor vehicle drivers.

DATA SOURCES: Information was derived from a search of MEDLINE (the National Library of Medicine database of over nine million articles published in 3,900 biomedical journals), Transportation Research Information Service (TRIS), and Bibliographic Electronic Databases of Sleep (BEDS) databases from 1975 through 1997 and from manual review of the reference lists in relevant journal articles, government publications, conference proceedings, and textbooks.

DATA SYNTHESIS: Driver sleepiness is a causative factor in 1 percent to 3 percent of all U.S. motor vehicle crashes. Surveys of the prevalence of sleepy behavior in drivers suggest that sleepiness may be a more common cause of highway crashes than is reflected in these estimates. About 96 percent of sleep-related crashes involve passenger vehicle drivers and 3 percent involve drivers of large trucks. Risk factors include youth, shiftwork, alcohol and other drug use, over-the-counter and prescription medications, and sleep disorders.

CONCLUSIONS: Increased awareness of the relationship between sleepiness and motor vehicle crashes will promote the health and safety of drivers and highway users. Physicians can contribute by encouraging good sleep habits, recognizing and treating sleep-related problems, and counseling patients about the risks of driving while sleepy. To protect public health and safety, the American Medical Association recommends continued research on devices and technologies to detect the signs of sleepiness and prevent the deterioration of driver alertness and performance. Educational programs about the risks of falling asleep while driving are needed for physicians, the public, and commercial truck drivers.

Dinges, David F. (1995). An Overview of Sleepiness and Accidents. *Journal of Sleep Research 4* (Suppl. 2), 4-14.

This paper explores the relationship between the scientific basis for sleepiness and accidents related to human error. The author warns of current and future adverse human, environmental, and economic impacts from transportation and industrial accidents arising from workplace performance errors, focusing particularly upon 24-hour industries and operations.

The author notes that studies estimate the contribution of fatigue to accidents in general ranges from 1 to 2 percent to 41 percent. Neither estimate is definitive, and "more data are needed on the incidents of sleepiness relative to the incidence of accidents, and on the contribution of fatigue-related performance errors to accidents." (p. 5) He posits that sleepiness may contribute to more that 1 to 2 percent because the definition of "contribute" often encompasses both the primary cause of the performance error, as well as an interacting factors leading to the adverse outcome. Dinges points out that some performance effects can occur without microsleeps, performance has been shown to decline as sleepiness increases. *"A loss of 10 percent in the detection of salient visual stimuli (e.g., 'slow speed' signage) and a 10 percent increase in reaction time (e.g., stopping to avoid a rear-end collision) both of which can be demonstrated in even moderately sleepy persons (Dinges 1992) may contribute to many traffic and work-related accidents that are otherwise attributed to operator inattention."* (p. 6)

Dinges notes there is no consensus on the contribution of fatigue to motor vehicle crashes. While acknowledging the NHTSA figures of 4.4 percent of single-vehicle roadway departure crashes involving drowsy drivers, he notes that single vehicle non-alcohol-related crashes accounted for 27 percent of all crashes (1993 data) and that "sleepiness may contribute to more of these crashes than current estimates allow." He expresses a need for incidence data relative to driving by time-of-day. He also notes significantly higher attribution of fatigue as a contributing factor in motorway crashes, fatal crashes on motorways, fatal-to-truck-driver crashes. In the current state of crash reporting, he notes that analyses of single-vehicle crashes assign causality to occupants' statements and it is not often determined, or it is not determinable, whether sleepiness was present.

Najm, W., Mironer, M., Koziol, J., Wang, J-S., & Knipling, R.R. (1995). *Examination of Target Vehicular Crashes and Potential ITS Countermeasures.* (Report No. DOT-HS-808) Washington, DC: National Highway Traffic Safety Administration.

This report summarizes results of a project to identify crash causation factors and to apply appropriate intelligent transportation system collision-avoidance concepts. The preliminary analysis considers nine major crash types. Cases were gathered from a sample of 1,183 crashes from the NHTSA General Estimates System (GES), Fatality Analysis Reporting System (FARS), and Crashworthiness Data System (CDS) data bases. The statistical analysis aggregates all vehicle types.

Target crash causes were determined based on in-depth reviews of 554 CDS files and 133 GES police accident reports (PARs), excluding reduced visibility crashes. Although some crashes may have had multiple contributing circumstances, only one was assigned based on the analysts's judgement.

For non-intersection crashes, excluding backing, the following causal factors were assigned to the target crash samples (Table 3-3, p. 3-5):

- Inattention: 56 percent of rear-end; 3.8 percent lane-change; 15.5 percent single-vehicle roadway departure; 17.8 percent opposite-direction.
- Looked-did not see: 61.2 percent lane-change; 0 percent all other types listed above.

- Driver asleep: 11.8 percent single-vehicle roadway departure; 0 percent all other types listed above.

Additional analysis indicated a combination of following-too-closely and driver inattention contributed to 19.4 percent of the rear-end crashes. Tailgating was recorded by the study's analyst as the primary crash cause. The opposite-direction crash sample "included a number of cases listed under driver inattention that could not be specifically determined (distraction, daydreaming, or other). Thus, driver drowsiness might have been a factor."

Reviewer's Notes: The researchers appeared to make a deliberate choice to assign only a single causal factor to a given crash, and there was no assignable driver state for cases that did not meet the criteria for "asleep." Therefore, there is a strong possibility that contributing factors such as drowsiness and fatigue might be underassigned.

CMV Driver Fatigue Contribution to Commercial Motor Vehicle Crashes

We must carefully consider the differences between commercial motor vehicle (CMV) involved accidents/crashes, exposure rate differences between CMVs and other vehicles, and especially the severity of crash outcomes. The publication *National Safety Council 1998 Accident Facts* (1999) considers the differences between daytime and nighttime highway accidents: *About half of all motor-vehicle deaths occur during the day and half occur at night. Death rates based on mileage, however, are 4.07 times higher at night than during the day.* (p. 90)

Most of the studies of driver fatigue as a factor in CMV crash involvement concentrate on long-distance operations. This has the effect of segregating the crash universe and study populations in four important ways. First, most long-distance operations involve tractor-trailer combination vehicles, rather than single-unit CMVs. (Exceptions, where local operations utilize combination-unit vehicles, include grocery store distribution and gasoline deliveries.) Combination vehicles, because of their articulation and larger mass relative to other vehicles, are more prone to crashes with more severe outcomes. Secondly, most of the roadway exposure of these vehicles is on limited-access highways such as the Interstate network, tollways, and expressways with higher posted speed limits, less traffic, and a more uniform (and barren) visual environment. Thirdly, many, but not all, local operations allow drivers to maintain regular schedules coinciding with the operations of their employing motor carrier's clients. Finally, the long-distance driver may spend a larger proportion of the work cycle driving — although many are responsible for loading and unloading the freight they carry. In short, the perceived and documented contribution of driver fatigue to CMV safety is likely to be very much a function of the type of operation, the type of roads driven, and, perhaps to a lesser extent, the type of vehicle driven.

Campbell, K. (1988, November). *Evidence of Fatigue and the Circadian Rhythm in the Accident Experience.* Paper presented at the U.S. Department of Transportation Symposium on Truck and Bus Driver Fatigue. Washington, DC.

Campbell notes that the coding of the "cause" of accidents in existing [i.e., contemporary with his presentation] data provides very little information that directly addresses fatigue. He believes it may not be possible or practical to identify single causes for most accidents, generally taking the point of view that accidents are a consequence of many different factors, all coming together at the same time. Campbell offers an alternative approach based on fatigue and circadian effects on vigilance performance, considering influences of extended time on task and circadian rhythms. (pp. 1-2)

Campbell performed his analyses to consider progressively larger subsets of accident data. He normalized rates according to travel distribution to determine under- and over-involvement.

For dozing-driver crashes, Campbell noted the trips took place mainly at night. On the other hand, the travel distribution for all crashes shows less variation by time-of-day, although there is a small peak around mid-day. (p. 5) This pattern diminishes for the ran-off-road crash subset, diminishes further for single-vehicle crashes, and shows no time-of-day trend for the aggregate of all crashes. (p. 6)

Campbell cautions that accident trips will overrepresent the amount of nighttime travel, and underestimate the resulting risk of crashes. (p. 7) "Exposure estimates developed from accident trips will be biased so as to under-estimate the risk associated with these factors." (p. 9)

The following studies assess causal and contributory roles of driver fatigue in road vehicle crashes.

Transportation Research and Marketing (1985). ***A Report on the Determination and Evaluation on the Role of Fatigue in Heavy Truck Accidents.*** **Washington, DC: American Automobile Association Foundation.**

This study involved an assessment of 231 crashes from 1983 and 1984 of six western States (AZ, CA, ID, NV, OR, UT), involving Classes 7 and 8 commercial motor vehicles towed from the scene. The researchers' objectives were to determine (1) if the presence of driver fatigue could be identified; and (2) if that determination was within the scope of a routine crash investigation, did the crashes involving fatigue occur frequently enough to justify increased preventive measures.

The authors used the following criteria: *Fatigue is defined as being reasonably present after 15 or more consecutive hours of on-duty or defined activity time. Fatigue is deemed to be a factor if non-professional, irrational actions occur at or beyond the 16th hour of continuous activity. Fatigue is defined as being reasonably present at the 16th hour since this is not only the first hour about the Bureau of Motor Carrier Safety (BMCS) [now Office of Motor Carrier and Highway Safety] upper limit of 15 hours total work time, it is also the last hour of two consecutive 8 hour workshifts.* (p. 2).

In order to reconstruct trips, the researchers requested investigating officers to provide copies of trip-related documents. They also contacted shippers, truck stops, motor carrier safety personnel, drivers, and drivers' families to verify times and activities. They estimated mileages using an industry guide and computed hours of driving on the basis of 50 miles per hour travel speed. The researchers intended to hold the standards of judgment to a conservatively high level.

The researchers stated they were able to generate sufficient data from 221 of the 231 crash reports they reviewed to permit them to determine probable presence of fatigue. Of the 221 crashes, they determined 59 percent were fatigue-related with 41 percent indicating fatigue as a primary or probable cause. Truck mechanical problems were indicated in 18 percent of the sample of 231 crashes. Truck driver alcohol impairment was cited in 4 percent of the crashes. Fatigue was cited as a probable cause in 23 crashes that also cited mechanical problems and in 6 crashes where alcohol use was involved.

Jones, I. & Stein, H. (1987). ***Effect of Driver Hours of Service on Tractor-Trailer Crash Involvement.*** **Arlington, VA: Insurance Institute for Highway Safety**

The authors performed a case-control study of crash-involved trucks and a comparison sample matched by characteristics of roadway, time of day, and day of week. They included all crashes in Washington State from June 1984 through July 1986 that met certain criteria: they involved trucks with gross vehicle weight ratings (GVWR) of over 10,000 lbs, occurred on interstate highways, and resulted in personal injury or property damage of at least $1,500.

The crash-involved trucks were inspected by Commercial Vehicle Enforcement Section (CVES) officers for mechanical defects. One week post-crash, CVES inspected three comparison trucks at an inspection site set up in close proximity to crash site. The trucks were pulled from the traffic stream approximately 30 minutes before the crash, at the time of the crash, and 30 minutes post-crash.

This analysis involved only tractor-trailer CMVs and excluded cases where the control vehicles were not tractor-trailers. The authors computed odds ratios with 95 percent confidence intervals for crash involvement. They developed a logistic regression model to assess simultaneous effects of different factors. The factors included crash configuration, driver age, hours of driving (2-hour blocks with last block "greater than 8 hours"), logbook violations (citation only or driver out-of-service), carrier type (common, contract, private), inter- or intrastate operation, truck load (partial, full, empty), and fleet size (small, 1-5; medium, 6-25; large, over 25 vehicles).

The authors found higher relative risks associated with over eight hours of driving, hours-of-service violations, interstate compared with intrastate motor carriers, young (under 30) compared with older drivers, and CMVs with equipment defects.

Frith, W.J. (1994). A Case Control Study of Heavy Vehicle Drivers' Working Time and Safety. Victoria, Australia: *Proceedings, 17th Australian Road Research Board Conference, Part 5,* 17-30.

This paper presented the results of a case-control study of heavy motor vehicle crashes in New Zealand. Cases was extracted from the Land Transport Safety Authority Traffic Accident Report and the Commercial Vehicle Investigation Unit (CVIU) data bases for the period 1988-1990. Control samples were collected on or near the anniversary dates of the crashes on the same locations, and during the period June 1992 through July 1993. CVIU officials gathered data from the drivers' logbooks (total elapsed time, driving time, and on-duty time since the drivers' last period of 24 hours off) and obtained other information about the driver and the vehicle.

The author stated "In this study, there were very few observations in which hours restrictions were violated. This suggests that falsification may have occurred." (p. 22). The New Zealand hours of service regulations require a driver to have 10 hours continuous rest in each 24 hours, a maximum of 11 driving hours, and a maximum working day of 14 hours. The weekly driving limit is 66 hours; the working limit is 70 hours. A 30-minute break is required after 5.5 hours of driving. The author notes that "driving hours" included this break (p. 22).

Among other observations, Frith noted an increase in relative accident risk after a working time of 9 hours or more. He notes *However, there are few observations in the area of the curve relating to longer times behind the wheel, so the shape of the risk curve in these regions is not well established. Also, any falsification of log-book entries would be likely to involve the movement of actual driving times from the illegal (>11 hours) into the legal region, and involve the crash sample to a greater extent than the control sample.* (p. 26)

Frith's conclusions included the following: crash involvement showed a statistically significant increased risk after about 8 hours of driving; it tended to be higher for smaller trucks than for larger ones, reflecting their use in congested urban environments; and younger drivers were involved in more crashes than older drivers. He did not find the following factors to be statistically significant relationships to crash risk: total elapsed time, on-duty hours worked, or driving hours worked since the last 24-hour off-duty period; on-duty hours worked since the driver's last 10 hours off-duty.

Reviewer's Notes. This study's analyses did not consider the time of day when crashes occurred, differences between urban and non-urban crashes, nor the types of non-driving activities the drivers performed as part of their work. It is somewhat surprising that a statistically significant relationship was found for a day's driving time but not for the day's on-duty time. One possible reason was that the selection of control cases in this study was not as closely controlled for type of vehicle (surrogate for type of operation) or direction of travel.

McCartt, A.T., Hammer, M.C., Fuller, S.Z., Kosa, & M., Merkerka, Y. (1997). ***Study of Fatigue-Related Driving among Long-distance Truck Drivers in New York State: Volume 2, Analysis of Crash Data.*** **Albany, NY: Institute of Traffic Safety Management and Research.**

This was a study of 1995 large-truck (over 10,000 lbs) crashes in New York State. Of 2,758 truck drivers involved in crashes, 53 were coded as fatigued or having fallen asleep — 70.6 percent of drivers with the condition coded other than "normal."

Compared to other types of truck crashes, the fatigued/asleep crashes were more likely to have occurred on a dry roadway, a divided highway, and a full-access-controlled roadway. The times of the crashes were more likely to be between midnight and 5:59 a.m. The driver was more likely to be young (25-34 years) and licensed by a state other than New York. The first non-collision event was most likely to be leaving the roadway. The first collision event was more likely to have involved striking a fixed object. Outcomes of fatigue/asleep crashes appeared to be similar to other types of crashes — about 2 percent involved fatalities and about 40 percent involved injury.

Federal Highway Administration (1999). *Crash Problem Size Assessment Update: Large Truck Crashes Related Primarily to Driver Fatigue.* (Research Note, Office of Motor Carrier and Highway Safety, Federal Highway Administration) Washington, DC.

(Author's Introduction) This research note presents a summary of available statistics relating to the percentage of large truck crashes and fatal large truck crashes that are primarily related to driver fatigue, drowsiness, or "asleep-at-the-wheel." Because of the many difficulties involved in precisely estimating these percentages, range estimates rather than point estimates have been derived. The statistics are organized along two dimensions: large truck body type and crash severity. The two major large truck types examined are combination-unit trucks and single-unit trucks. The two crash severity levels addressed are all police-reported crashes and fatal crashes. Within the fatal crash category, statistics are further subdivided by location of fatality. Fatal truck crashes may involve either a fatality to an occupant of the truck (almost always the driver) or a fatality outside the truck (occupants of the other involved vehicles, pedestrians, or pedalcyclists).

The author notes that although crash statistics derived directly from police accident reports are generally believed by the crash analysis community to be underestimates, these statistics represent a "lower bound" measure. Analyses based upon comparisons of fatigue-related crashes assessed in four studies *(1982-84 National Accident Sampling System (NASS) Statistics, the 1990 National Transportation Safety Board's Study of Fatal-to-the-Driver Large Truck Crashes;* and two recent studies, (Knipling and Wang (1995) and Wang, Knipling, and Goodman (1996)), have also yielded higher percentages of fatigue-related crashes than that indicated in comparable police accident report based samples.

(Author's Summary) *"Based on the comparisons of the four studies, FHWA OMCHS believes that working estimates of the percentage range of large truck crashes principally related to fatigue can be derived from the range of the above correction factors — 1.4 to 3.1 multiplied by the applicable PAR statistics."*

Saccomanno, F.F., Shortreed, J.H., & Yu., M. (1996). Effect of Driver Fatigue on Commercial Vehicle Accidents. In F. Saccomanno and J. Shortreed (Eds.) *Truck Safety: Perceptions and Reality,* (pp. 157-174), Waterloo, Ontario: Institute for Risk Research, University of Waterloo.

The authors of this study investigated the contributions of acute [their term: industrial] fatigue and circadian effects to truck accidents in the Province of Ontario. Saccomanno and his coauthors used databases of 1988-1989 police accident reports, Provincial highway inventory and traffic volume data and the Ontario Commercial Vehicle Survey. This last source provided data on commercial motor vehicle driver demographics, routes, working hours, and other factors. They compared trips and accidents in northern and southern regions of Ontario (surrogate comparisons of overnight trips over 1000 km (1600 mi) compared to mainly daytime trips of 600 km (900 mi) or less), hours of driving "without rest" as reported by drivers in roadside surveys, and day compared to night driving (surrogate for circadian-induced fatigue effects).

The authors found a higher overall risk associated with longer 85th percentile "driving time without rest" of 9.5 hours or longer. They also noted large and highly statistically significant differences between nighttime and daytime single-vehicle accidents and a higher proportion of these accidents on routes with long driving times. Rates for nighttime single-truck accidents were 3.3 times higher than daytime single-CMV accidents in Northern Ontario; 5.7 times higher for nighttime accidents in the north than in the south; and 13 times higher when comparing daytime-southern Ontario and nighttime-northern Ontario accidents.

The authors believe their results suggest a correlation between long distance driving and acute fatigue, and acute fatigue's role as a contributing factor to single-truck accidents. They also note what they consider a cumulative effect of circadian fatigue from nighttime driving and acute fatigue from long driving hours.

The authors provided several caveats to their findings. Although they noted a statistically significant difference between Northern and Southern Ontario accidents, they could not investigate details of trip lengths or the amount of nighttime travel. They stated the relationship could also have been influenced by factors such as longer winter conditions in the northern tier. They also raised concerns about the methods used by police to establish "fatigue" as a factor on accident reports and note that their traffic volume estimates were based on one-day sample survey data.

Hamelin, P. (1987). Lorry Driver's Time Habits in Work and Their Involvement in Traffic Accidents. *Ergonomics 30* (9) pp. 1323-1333.

This paper summarizes research based upon a survey of 1000 heavy-goods-vehicle drivers undertaken in 1982-1983 and a review of a representative sample (1/25) of accident reports filed with the French transportation safety agency, Institut National de Researche sur les Transports et leur Securite (INRETS), during that same period.

Hamelin divided the drivers into "Transport Branch" [equivalent to for-hire drivers] and "Other Branches" [equivalent to private fleet drivers]. The "Transport Branch" drivers were more likely to be away from home 2 days or more. They also had the longest working times, proportion of time spent driving, lowest amount average sleep time (percentage less than 6 hours). Most of these drivers operated on irregular schedules and were more likely to be on the road between 8:00 p.m. and 6:00 a.m. They were overrepresented in accidents relative to their share of the driver population, their driving time, and the length of their work hours.

Hamelin computed accident risk rates according to the time of day, the time on task, and whether the drivers were in the "Transport" or "Other" occupational categories. For all drivers, the risk rate was nearly double (1.82 times baseline) after 11 hours of work. For "Other Branch" drivers who had worked over 11 hours, it was over four times as high during the period 8:00 p.m. and 7:00 am. The crash risk was the lowest during the period 8:00 a.m. to 7:00 p.m. and after less than 11 hours of work.

Hamelin believes the findings suggest the risk of an accident might be more dependent on cumulative fatigue rather than the short periods of work time prior to a crash noted on the accident reports (the forms required an entry of time since the last stop, rather than the time since the beginning of a trip). He also posits that the "Transport Branch" drivers have more experience with long and irregular driving hours and are "better able to manage their fatigue ... especially at night." (p. 1331).

Folkard, S. (December 1995). 'Time on Shift' Effects in Safety: A Mini-Review. (Abstract). *Shiftwork International Newsletter* 12(1) p. 16.

In this research abstract, Folkard cited the pattern of crash involvement by truck drivers studied by Hamelin (1987) [study summarized above] indicating higher risk in first 4 hours and again after 12 hours.

Folkard asks if there might be an "optimal" length of shift. Based upon five published studies indicating hour data on exposure-corrected accident rates, he determined a relative risk of 1 over the first 8 hours of the shift and fitted an exponential function to relative risk of crashes over time. He found the "safest system" to be based on 6-9 hour shifts, with an accident risk over a 12-hour shift about 15 percent higher than on an 8-hour shift. However, he noted the function underestimated the risk during the second through fourth hours.

Folkard, S. (1997). Black Times: Temporal Determinants of Transport Safety. *Accident Analysis and Prevention 29* (4), 417-430.

In this paper, Folkard provides a series of analyses on the timing of transportation accidents to assess time-based contributors to accident risk.

Folkard reviewed the time-of-day trends in accidents and workplace errors from studies concerning road, maritime and industrial operations. Like other researchers, he noted a circadian rhythm to these accidents, with a major peak around 0300 and a secondary peak at 1500. He then compared sleep-propensity data from other studies derived from performance tests, noted differences between these data and accident risk, and posited a time-on-task effect. Using z-score analysis (a type of statistical normalization) of data from three studies that provided exposure-based data, he determined the existence of what he termed "residual peaks" in accident risk between 2 and 4 hours into the duty/driving period. During those times, estimated risk increased approximately 20 percent relative to an 8-10 hour workshift, and did not reach the same level again until the duty period reached 14 hours.

Folkard offers a possible explanation for the "residual peaks:" they could reflect time-on-task effects coupled with the operator's need to "reautomatize" skills for automatic processing of certain types of information. Although he notes the relative risks of different lengths of duty period should be considered cautiously because of the limited data they were derived from, he urges further research into the causes of the peaks, as well as development of countermeasures.

Gillberg, M., Kecklund, G., and Akerstedt, T. (December 1995). Sleepiness and Performance of Professional Drivers in a Truck Simulator — Comparisons Between Day and Night Driving. *Shiftwork International Newsletter 12*(1) p. 20.

This abstract presents partial analysis of a simulator-based study on driving performance, physiological state, and subjective sleepiness ratings. Nine professional drivers participated in a study that incorporated a counterbalanced design to compare day driving, night driving, night driving with a 30-minute rest period, and night driving with a 30-minute nap. The drivers drove each condition for 3 consecutive 30-minute periods. The simulated driving environment included a narrow road with hills, rolling terrain, and oncoming traffic; the subjects were requested to "drive" 70 kph (43.75 mph). Driving performance information recorded included mean speed, standard deviation of speed, and standard deviation of lane position. Subjective sleepiness was rated according to the Karolinska Sleepiness Scale.

The researchers found statistically significant differences between day and night driving for speed variation, standard deviation of lane position, and subjective sleepiness ratings. They did not find differences among the 3 night conditions.

Reviewer's Notes: This is one of very few studies that specifically assessed differences between day and night driving. However, the driving periods studied were relatively short (90 minutes in each setting) and the sleep status of the subjects prior to their participation was not noted in the abstract.

Blower, D. & Campbell, K. (1998). *Fatalities and Injuries in Truck Crashes by Time of Day*. (Report No. FHWA-MC-99-098). Washington, DC: Federal Highway Administration.

(Authors' Abstract) The Federal Highway Administration is currently considering proposals to change the regulations governing the hours-of-service of commercial truck drivers. The purpose of the present report is to provide information on the distribution of crashes, injuries, and fatalities by time of day and to measure the consequences of truck crashes by time of day, both to truck occupants and to other road users. Older sources of VMT (vehicle miles of travel) data are used to illustrate the relative risk of day and night travel.

About 20 percent of all fatal crashes and fatalities and 10 percent of all injuries involving a long-haul truck (tractor pulling at least one trailer) occur between midnight and 6:00 a.m. Crashes at night tend to be more severe, with about 435 injuries per thousand crashes between midnight and 6:00 a.m., compared with 320 injuries per thousand for the remainder of the day. There are about three times as many fatalities per thousand crashes from midnight to 6:00 a.m.

Truck travel estimates by hour of the day are not currently available. Using exposure data classifying night as 9:00 p.m. to 6:00 a.m., truck travel during that period is associated with a relative risk about twice that of the rest of the day. Truck driver fatigue in single-vehicle fatal crashes is a significant factor. Driver fatigue and alcohol use in nontruck drivers also form a significant component of the higher risk of night travel. Almost 40 percent of the nontruck drivers in multiple-vehicle crashes with trucks between midnight and 3:00 a.m. had used alcohol, compared with 2.7 percent of the truck drivers. Fatigue was also coded more often for nontruck drivers than for truck drivers in multiple-vehicle crashes.

Hackman, K.D., Larson, E.E. & Shinder, A.E. (1978). *Analysis of Accident Data and Hours of Service of Interstate Commercial Motor Vehicle Drivers*. Washington, DC: Federal Highway Administration. (NTIS PB 286 718)

The objectives of this study were to assess the relationship between driver HOS and accident incidence and to relate the results to the existing HOS regulations.

Data from 26,149 interstate truck and bus crashes occurring during 1976 were analyzed. The authors obtained Motor Carrier Accident Report Forms 50-T and 50-B (the Federal

Motor Carrier Safety Regulations required motor interstate motor carriers to file these forms until 1994) and supplemental forms for seven classes of crashes (ran-off-road, overturn, out of control, rear-end, opposite sideswipe, fixed object, driver-dozing condition). Exposure, demographic, and other factors were estimated from a 1977 FHWA-sponsored study, *Nationwide Survey of Truck and Bus Drivers*. Crash distributions were compared to a theoretical distribution assuming a uniform number of crashes would occur for each [hourly] time increment of the trip if fatigue were not a factor. Trip durations were estimated from the number of driving hours between 8-consecutive-hour off-duty periods and the number of driving hours from the end of that off-duty period to the trip destination.

The main results indicated no consistent patterns to imply that driving hours alone were related to the frequency or severity of truck crashes; planned trip length and crash occurrence were not significantly different between fatigue-related and other crashes; the vast majority of drivers (98 percent of sample) were in compliance with the 10-hour driving limit in the HOS regulations; and the amount of the last extended [recorded] rest did not appear to have a consistent influence on crash outcome.

The authors provided numerous caveats and cautions. This reviewer highlights several: two-driver operations could not be compared for actual and expected crashes because anticipated driving time to the destination was not reported; instructions for the Form 50-T included marking "not applicable" for hours driven until the crash if the 8-hour off-duty period utilized the sleeper berth; there was no space on the Form 50-T to code trips over 12 hours long; and the time-of-day of the off-duty period appeared not to have been coded in the data, nor was it compared with the time-of-day the crashes took place.

Kecklund, G. & Åkerstedt, T. (December 1995) Time of Day and Swedish Road Accidents. ***Shiftwork International Newsletter 12*** **(1) p. 31.**

The objective of this study was to examine the effects of time-of-day on four types of accidents. Data was obtained for all accidents involving an injury and all truck accidents for the period 1987-1991. Exposure was derived from Swedish national motorway data. Risk ratios were computed against a baseline time period of 8:00 a.m. - 4:00 p.m.

The results included the following: Single vehicle accidents where alcohol was not a factor peaked at 4:00 a.m. at 13 times the baseline level. The risk of a fatal accident was

35 times the baseline level at 4:00 a.m; severe (27 times) and minor (19 times) injury accidents also peaked at that time. Risk ratios for overtaking-vehicle and oncoming vehicle accidents also peaked at 4:00 a.m.., but the ratios were considerably lower (3-4 times). For trucks, there was a peak of 3.8 times the baseline risk ratio for single-vehicle accidents between 3:00 a.m. and 5:00 a.m.

Lin, T., Jovanis, P., & Yang, C. (1994). Time of Day Models of Motor Carrier Accident Risk. *Transportation Research Record 1467, pp. 1-8.* Washington, DC: Transportation Research Board

The authors developed a time-dependent logistic regression model to assess accident probability. They developed a series of versions of their model, including time as a main effect, a covariant, and an interaction term. They built their model using data from a national less-than-truckload motor carrier's "pony express" type of operation. In this type of operation, drivers would make an outbound trip from the home terminal to another terminal, drop their trailer, pick up another trailer, and return to the home terminal at the end of a work shift.

Lin and coauthors found that driving time had the strongest effect on accident risk. The first 4 hours had the lowest risk; after the 4th hour, the risk increased by approximately 50 percent or more until the 7th hour; the 8th hour showed approximately an 80 percent increase over the first 4 hours; the 8th hour, approximately a 130 percent increase. Driving experience had the next strongest effect: drivers with more than 10 years driving experience showed a consistently lower risk.

Time of day effects were not as strong. Peak accident risk periods were 4:00 p.m. to 6:00 p.m.; midnight to 2:00 a.m.; 6:00 a.m. to 8:00 a.m.; and 8:00 p.m. to 10:00 p.m. Daytime driving, especially during the period 10:00 a.m. to noon, resulted in significantly lower accident risk.

Reviewer's Notes: The authors assume the risk factors and outcome of interest are independent of time. The authors also did not consider a driver's prior duty periods. From a standpoint of pure exposure-based risk, these assumptions are acceptable and even desirable. However, physiological factors related to driver state, especially prior sleep quantity and quality, influence the risk because the driver's state of alertness depends on them.

Jovanis, P.,P., Kaneko, T., & Lin, T-D. (1991). Exploratory Analysis of Motor Carrier Accident Risk and Daily Driving Pattern. *Transportation Research Record 1322.* Washington, DC: Transportation Research Board.

This study reported an exploratory analysis of crash risk based on a comparison of driving patterns used by a less-than-truckload motor carrier. Jovanis and coauthors used cluster analysis to assess driving patterns on accident- and non-accident trips from a sample of 1,066 drivers over a 6-month period in 1984 and 1985. They assigned the trips to nine patterns, the maximum possible based on available computing resources.

The cumulative duty and driving hours were relatively similar (range 7.8 to 8.4 driving hours daily). The drivers' daily on-duty-off-duty cycles ranged from 22.3 to 23 hours, indicating some circadian disruption. The highest daily risk was found to occur from 4:00 a.m. to 6:00 a.m. Elevated risk was found from midnight to 8:00 a.m.

According to the authors: *The two patterns with the highest risk of an accident were those that contained heavy driving during the prior three days and consisted of driving from 3:00 p.m. to 3:00 a.m. (Pattern 1) and from 10:00 p.m. to 10:00 a.m. (Pattern 8). The lowest risk was associated with driving from 8:00 p.m. to 6:00 a.m. but with limited driving on the prior three days.* (p. 27)

Massie, D.L., Blower, D., & Campbell, K.L. (1997). *Short-Haul Trucks and Driver Fatigue.* (Report FHWA-MC-98-016) Washington, DC: Federal Highway Administration.

The purposes of this assessment were to (1) define "short haul trucks" in several computerized data bases of truck demographics, usage, and crashes; and (2) examine the prevalence of driver fatigue in the crash data files and relate them to parameters defining short-haul trucking operations.

Massie and coauthors considered truck size (classes 3-6 compared with classes 7 and 8), local service (defined as trips under 50 miles), straight trucks compared to tractors and combinations of these factors in computing fatal crash involvement rates. When they considered local service alone, without regard to gross vehicle weight rating or vehicle class, they determined the fatal involvement rate on a per-vehicle basis for local service trucks to be

43 percent as high as the rate for over-the-road trucks. On a per-mile basis, local service trucks had a fatal crash involvement rate 1.8 times higher than over-the-road trucks.

The authors also analyzed crash data for driver fatigue involvement. They noted that fatigue is not commonly coded as a contributing factor, and that reported data may be incomplete because of the often-circumstantial nature of the evidence. Their data showed fatal involvements peaking in the period between 4:00 a.m. and 7:00 a.m. when 38.6 percent of all fatal-related involvements were found to occur. A secondary peak in fatigue-related involvements was found to take place between 3:00 and 5:00 p.m.

The authors summary includes this observation: *The prevalence of driver fatigue in fatal involvements shows no variation according to GVWR class and some according to vehicle type (higher percentage for tractors than straight trucks). The most variation is seen for trip distance. Driver fatigue is coded for 0.4 percent of trucks on trips of 50 miles or less compared with 3.0 percent of trucks on longer trips."* (p. 35)

Effects of Sleep Deprivation on Alertness and Performance

This section introduces a series of studies, mostly performed in laboratory settings but some assessing operational situations, that explore the relationships between the sleep obtained and subsequent performance. They can be summarized simply: a person who is sleepy is prone to perform more poorly on tasks requiring vigilance and decisionmaking than a person who is alert. The first group of eight papers deals with general effects of sleep loss on performance, while the last four studies focus on sleep fragmentation due to timing or the quality of the sleep environment.

Dinges, D.F. & Kribbs, N.B. (1991). Performing While Sleepy: Effects of Experimentally-Induced Sleepiness. In Monk T. (Ed.) *Sleep, Sleepiness and Performance.* New York: John Wiley & Sons [Ch. 4, pp. 97-128]

This book chapter presents a historical review of major research studies that have led to increased understanding of the relationships between sleep loss and human performance decrement. The authors focus upon laboratory studies involving human subjects exposed to moderate to severe sleep deprivation. They discuss performance decrements on tasks with different types of response characteristics, and the influences of circadian covariation as well as the characteristics of response tasks on outcomes. In those settings, they state: *The most powerful determinant of lapsing and decreased performance in a sleepy person is the required task duration . . . the longer the task duration, the greater likelihood that the performance will show evidence of impairment early on during sleep deprivation.* (p. 108)

Among the research the authors cite is work by Lisper & Kjellberg (1972) who found systematic increases in reaction-time and declines in performance after only one night without sleep. Dinges and Kribbs also cited other studies that found increased lapses, increased false-starts, and decreased attention allocation in sleep-deprived persons. On the other hand, they found that a number of studies in the literature that did not show effects of performance after sleep loss had several common elements: they were done on military personnel; they were physical tests rather than cognitive ones; the tests were administered infrequently; and the analyses were limited.

The authors acknowledge some researchers' belief that motivation can overcome or compensate for sleepiness while they point out the influences of the nature of the tasks performed, the incentives provided the test subjects and the amount of sleep deprivation prior to the tests. They conclude: *The point is that because motivational factors can be salient in demonstrating performance deficits from sleep loss, it does not follow that there is no reduced capacity to perform.* (p. 119)

Other aspects of performance the authors reviewed included the interaction of circadian and sleep deprivation. This combination of conditions resulted in the poorest levels of performance. They also discussed transitory performance impairment during sleep inertia, noting it is most severe after abrupt wakening, during the first half of the night, and following deep recovery sleep.

The authors state that as a person's physiological sleepiness from sleep loss increases, the person becomes more dependent on environmental stimulation to maintain wakefulness. They characterize a sleepy person's performance by its state liability — the increased fluctuation between alertness and lowered vigilance, drowsiness and microsleeps. The authors include driving as an example of a task requiring sustained attention and also requiring quick and appropriate responses to events.

Bonnet, M.H. & Arand, D.L. (1995). We Are Chronically Sleep Deprived. ***Sleep. 18*****(10) 908-911.**

This is an overview paper describing research findings of daytime sleepiness in laboratory and operational settings.

The authors report that data from laboratory studies indicate reduction of as little as 1.3 to 1.5 hours of nighttime sleep can result in a reduction in daytime alertness of up to one-third, measured by results on a Multiple Sleep Latency Test (MSLT)[2]. Other data indicate 17-57 percent of young adults have MSLTs less than 5.5 minutes; 28-29 percent of young adults report normal week night sleep times less than 6.5 hours compared to the 8.5 hours they actually needed and obtained in a study setting.

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[2] *The Multiple Sleep Latency Test is a test used to assess a persons' sleepiness tendency. The test is performed in a clinical setting, often the morning after a night of monitored sleep. A person is asked to lie quietly in a darkened room and to try to fall asleep.*

Shiftworkers and nightworkers sleep even less — 5.8 to 6.4 hours per day for permanently-assigned graveyard shift workers and 5.25 to 5.5 hours per day for rotating-shift workers when they work the night shift. Finally, 2 to 4 percent of middle-aged adults suffer from excessive daytime sleepiness associated with sleep apnea.

Bonnet and Arand conclude that one-third of normal adults have significant sleep loss, that the average self-reported sleep length of 7.2 to 7.4 hours is insufficient, and the common sleep length of 6.5 hours can have disastrous outcomes in terms of personal and societal costs.

Belenky, G., Penetar, D.M., Thorne, D., Popp, K., Leu, J., Thomas, M., Sing, H. Balkin, T., Wesensten, N., & Redmond, D. (1994). The Effects of Sleep Deprivation on Performance During Continuous Combat Operations. In *Food Components to Enhance Performance* (127-135). Washington, DC: National Academy Press.

This paper provides a description of sleep deprivation effects on laboratory subjects and on soldiers in a continuous combat operation.

The ability to do useful mental work declines by 25 percent for every successive 24 hours that an individual is awake . . . Referring to a study by Thorne et al. (1983) of subjects during 72 hours of total sleep deprivation . . . *During sleep deprivation, performance declines, but it usually declines in such a way as to preserve the accuracy of response at the expense of speed* . . . *In contrast, simple psychomotor performance and physical strength are unaffected.* (pp. 128-129)

The authors continue, *Brief fragmented sleep has little recuperative value and is similar to total sleep deprivation and its effects on performance.* (p. 129) The authors cite Bonnet's 1987 study where the sleep of normal volunteer subjects was disrupted every 2-3 minutes and the degree of their arousals were assessed in different ways (full awakening, change in posture, change in EEG patterns). *If fragmentation of sleep, even fragmentation of sleep with no obvious behavioral manifestations . . . destroys the recuperative value of sleep, then not only the duration but also continuity of sleep is important.* (p. 129)

Commenting upon the effect of sleep deprivation during simulated continuous operations on performance, the authors say, *Throughout the 36 hours, [the soldiers'] ability to accurately derive range, bearing, elevation, and charge was unimpaired. However after about 24 hours they stopped keeping up their situation map and stopped computing their* *preplanned targets immediately upon receipt. They lost their grasp of their place in the operation. They no longer knew where they were located relative to friendly and enemy units. They no longer knew what they were firing at. . .* (p. 132)

Dinges, D.F., Pack, F., Williams, K., Gillen, K.A., Powell, J.W., Ott, G.E., Aptowicz, C., & Pack, A.I. (1997). Cumulative Sleepiness, Mood Disturbance, and Psychomotor Vigilance Performance Decrements During a Week of Sleep Restricted to 4-5 Hours Per Night. *Sleep 20:*4 267-277.

In this laboratory study, sixteen healthy young subjects (mean age 22.9 years) volunteered to have their sleep limited in a laboratory setting for 1 week to "50 percent of their ideal sleep duration." Their baseline sleeps averaged 7.41 hours; restricted sleeps averaged 4.98 hours, and recovery sleeps, 7.91 hours. The restricted sleeps were about two-thirds as long as the subjects habitual sleeps. Their sleep duration was monitored using a combination of actigraphy, behavioral observation, and sleep logs. Sleep was only taken during nighttime hours, and daytime napping was permitted except for Multiple Sleep Latency Test (MSLT) administration. The subjects were given cognitive performance, mood, subjective sleepiness, and MSLT tests at preplanned times during each test day.

The authors reported that the only statistically reliable subjective measure by time-of-day was the Stanford Sleepiness Scale (SSS). Other subjective sleepiness and mood measures did not show statistically significant changes. However, four of the five performance measures showed statistically significant variations by time of day. PVT performance measures showed significant variation across the days of sleep restriction.

Dinges and his coauthors reported the effects of sleep restriction on performance measures appeared to level off between the 2nd and 5th day of sleep restriction; for subjective assessments, between the 2nd and 6th day. The authors believe the subjects were undergoing an "adaptation" to sleep restriction following an initial shift to higher daytime sleepiness levels, and that this change may have resulted from changes to sleep itself during those periods (EEG was not monitored). However, by the 6th to 7th day performance was deteriorating and subjective sleepiness was increasing again. The authors note the linear nature of the trends indicate the performance changes are cumulative and they did not level off.

This study included a recovery period following the sleep-deprivation. The authors reported the SSS and profile-of-mood scores improved after one night of recovery sleep but the scores were still higher than after the baseline sleeps. Half of the subjects were given a second night of recovery sleep. Reviewing the results of subjective and objective assessments, the authors noted that: *Recovery from the effects of sleep restriction for seven days appeared to depend on obtaining two nights of recovery sleep* (p. 276).

The authors conclude: *At least within the conditions of these two experiments, therefore, cumulative nocturnal-sleep debt had an analog in cumulative diurnal sleepiness. This suggests that persons who experience limited sleep durations may be at risk for developing cumulative waking neurobehavioral deficits.* (p. 275)

Pilcher, J.J., & Hufcutt, A.I. (1996). Effects of Sleep Deprivation on Performance: A Meta-Analysis. *Sleep 19*(4) 318-326.

In this study, the researchers used meta-analysis, a quantitative analytical technique, to summarize the results of 19 original research studies. The studies used either short-term total sleep deprivation (less than or equal to 45 hours), long-term total sleep deprivation (greater than 45 hours), and partial sleep deprivation (less than 5 hours in a 24-hour period). In order for Pilcher and colleagues to include the studies in their analysis, the studies also had to use as dependent variables the results of either a cognitive performance task, a motor performance task, or a subjective mood scale. The authors of the candidate studies also had to report all their data and provide enough information for statistical computation of study size effect. Out of the 56 studies Pilcher and colleagues located, they reported that only 19 met all the criteria.

Our results confirmed that sleep deprivation has a significant effect on human functioning. By quantitatively combining across primary studies we found that the mean level of functioning of sleep-deprived subjects was comparable to that of only the ninth percentile of non-sleep-deprived subjects. (p. 323)

Pilcher and colleagues also noted cognitive performance was more effected by sleep deprivation than motor performance and mood was much more effected than either cognitive or motor performance. They also advised future research on partial sleep deprivation and circadian rhythms.

Dawson, D. & Reid, K. (1997). Fatigue, Alcohol, and Performance Impairment. ***Nature 388:*** **(17 July) 235.**

This laboratory-based study compared performance impairment on a cognitive psychomotor task between subjects in conditions of 28 hours of sleep deprivation and alcohol intoxication of up to 0.10 percent blood alcohol concentration (BAC). Forty subjects between 18 and 32 years old participated. The researchers used a performance test consisting of a computer-based tracking task where a cursor moving in an unpredictable manner had to be kept "centered" in the center of three concentric circles. Subjects arrived at the sleep laboratory, were trained to perform the tracking task, and slept overnight in the laboratory for approximately 8 hours before commencing the test periods.

The researchers calculated a linear decrements in performance approximately 0.74 percent per hour for the 10th through 26th hours of sustained wakefulness. The researchers stated they considered this methodologically appropriate "since there is a strong non-linear (circadian) component to the performance data and shiftworkers do not typically spend less than 10 or more than 26 hours awake." They also found a linear relationship between subjects' mean BAC and relative performance on the tracking task: mean relative performance deteriorated by approximately 5.8 percent at 0.05 percent BAC and 11.6 percent at 0.10 percent BAC.

Reviewer's Notes: Although the researchers have demonstrated an empirical equivalence between performance decrements due to alcohol intoxication and sleep impairment, there are serious concerns about the basis for the comparison. The use of alcohol prior to driving is prohibited under the FMCSRs for CMV drivers. The decision to use alcohol at all is a personal choice. On the other hand, the situation of driving while in a state of less than optimal alertness is often one that is influenced by circadian effects, working conditions, and economic imperatives. Although it may be tempting to equate performance decrements achieved between the two conditions, the simplistic nature of the comparison raises numerous public-policy and scientific concerns.

Belenky, G.L., Krueger, G.P., Balkin, T. J., Headley, D.B., & Solick, R.E. (1987). ***Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance: Review of the Literature and Strategies for Sustaining the Soldier in CONOPS.*** **(Report WRAIR-BB-87-1) Washington, DC: Walter Reed Army Institute of Research.**

This review report contains a literature review and recommended strategies for sustaining soldiers' performance under conditions of continuous operations.

Belenky and colleagues cite Johnson's (1982) catalog of aspects of tasks that make them sensitive to effects of sleep loss: duration (longer tasks are more sensitive); difficulty (more cognitively-demanding tasks are more sensitive); feedback (task is more resistant to sleep loss . . . if present and immediate); practice (well-practiced tasks are more resistant); complexity (tasks requiring divided attention or a sequence of mental operations are more sensitive); learning and memory (short-term-memory-dependent tasks are highly sensitive); and work-rest schedule (rest periods, where continuous concentration on task is not required, can slow the decline in performance). Although other factors, such as high levels of interest in the task and motivation, can improve performance, the authors of the report state: *"However, it is important to note that no amount of interest, motivation, or personal effort of any kind will be completely effective in counteracting the effects of sleep loss."* (p. 1-3)

The authors comment on the need for sleep: . . . *the vast majority of adults require 6-8 hours of sleep each night to maintain adequate, normal levels of daytime arousal . . . [Citing Friedman, et al. 1977] Normal adults are capable of reducing their total sleep time by as much as 1-2.5 hours below baseline for several months without affecting performance on most tasks, but chronic fatigue (with its attendant loss of motivation and initiative) is the price that is paid. Chronic restriction of sleep length to less than 4.5 hours each night is not possible* . . .(p. 1-10)

Concerning naps, the authors note that . . . *Naps can have a prophylactic effect against subsequent sleep loss* . . . (pp. 1-13). The authors cite research by Nicholson, et al. (1985) noting positive effects on daytime performance of subjects who took four-hour early-evening naps prior to all-night sleep deprivation or morning naps following all-night sleep deprivation. They also cite Dinges, et al. (1985) on timing of naps: naps taken early in the period of sleep loss are more effective than naps taken later, and the optimal time for naps in terms of recuperation is the circadian trough.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., & Mackie, R.R. (1996). ***Commercial Motor Vehicle Driver Fatigue and Alertness Study.*** **(Report No. FHWA-MC-97-002) Washington, DC: Federal Highway Administration.**

The objectives of the Commercial Motor Vehicle Driver Fatigue And Alertness Study (DFAS) were to (1) establish measurable relationships between CMV driver activities and physiological and psychological indicators of fatigue and reduced alertness; (2) identify and evaluate legal, safe, and effective alertness-enhancing countermeasures to fatigue; and (3) provide a scientifically valid basis to determine the potential for revisiting the current hours-of-service requirements.

The study was a major scientific research effort to gather information on a broad range of interrelated items in the driver-vehicle environment, including driver performance and vehicle operating parameters, objective and subjective measures of driver psychological and physiological state, and vehicle operating environment (such as cab temperature, air quality). It was a field research activity performed under "real-world" conditions (i.e., revenue runs) that compared 4 distinct driving schedules designed to replicate a range of motor carrier operations: “baseline,” regular daytime schedule, 10 hours of driving in a 24-hour period; “operational” schedule which starts and ends earlier each succeeding day to maximize distance traveled while adhering to the 10-hour driving limit and the 8-hour off-duty requirement; and two 13-hour driving schedules undertaken in Canada: midnight-start and midday-start.

The study also was done to assess the feasibility of countermeasures, defined as devices which monitor the driver's behavior or the vehicle’s operation, and actions to enhance the drivers’ level of alertness, delay the onset of fatigue, or mitigate its effects.

Finally, the study was an international research venture developed in partnership with the FHWA’s stakeholders in the motor carrier industry.

It is important to realize the study had certain limitations. It was designed to be representative — but it could not be an exhaustive motor carrier industry-wide assessment. It was designed to serve as a baseline for additional research — but it cannot form, *on its own*, a basis for changes in the hours-of-service regulations. It reviewed and assessed possible alertness-enhancing countermeasures — but it cannot form a basis for *requiring* their use. Finally, the study was designed to facilitate observation and assessment of driver fatigue related to driving time and driving schedules. It was not designed to compare driver fatigue with impairment from other causes such as alcohol, drugs, or disease.

Numerous measures were taken of the 80 participating CMV drivers' physiology, alertness, and performance during driving periods and of their physiology during off-duty sleep periods. They included: driving task performance (lane tracking, steering wheel movement); driving speed and distance monitoring to aid in data analysis; performance on three microcomputer-based tasks related to safe driving, measuring drivers' cognitive processes, hand-eye coordination, reaction time, and vigilance; continuous video monitoring of the drivers' face and the view of the road ahead; physiological measures (heart rate and electroencephalograph measures during driving and sleep periods; respiration and blood oxygen saturation level during sleep; and body temperature during driving periods); driver-supplied information, including sleep questionnaire, log of stops, meals, noteworthy driving events, and a regular self-assessment of fatigue and mood; and tractor cab environment (temperature, relative humidity, 8-hour concentrations of carbon monoxide and nitrogen dioxide).

Data collected covered more than 200,000 miles of driving, with some 4,000 hours of video data, 9,000 hours of physiological recordings, and 700 megabytes of real-time truck computer records. Statistical analysis focused upon evaluations of the effects of the four driving schedules and related factors such as hours of sleep obtained on the measures of driver alertness and performance listed above.

Research findings comprised several categories as follows:

Circadian rhythms and fatigue: The strongest and most consistent factor influencing driver fatigue and alertness was the time of day. Compared to driving at other times, night driving (midnight to 6:00 a.m.) was associated with more video observations of driver drowsiness, poorer lane-keeping, and worse results on tests of mental performance. Most notably, there was no difference in the amount (prevalence) of drowsiness observed in video records of comparable daytime segments of the 10-hour and the 13-hour trips. Nighttime segments could not be similarly analyzed because the study design did not provide for this comparison.

Drowsiness during driving: Clinical-level analysis of brain-wave data collected during driving periods showed a number of intermittent apparently-drowsy episodes during two trips involving different drivers (or 0.55 percent of the 360 trips in the study), totaling just over 19 minutes out of roughly 4,000 hours of driving video (or 0.008 percent of the driving-time data collected). Driving periods between midnight to 6:00 a.m. had up to eight times the proportion of video data judged drowsy as data recorded between 9:00 a.m. and 9:00 p.m. There was sizable variation in the amount of drowsiness based on video observations: 11 drivers out of the 80 participants (14 percent) accounted for more than half (54 percent) of all the observed video-drowsy samples.

There were *no* crashes during the study.

Driver self-awareness (subjective assessment) of fatigue: Drivers tended to rate themselves more alert than their performance tests indicated. Although some of the performance data did not show a clear-cut relationship to driving time (time on task), drivers' self-ratings *did* correlate significantly with time since the start of the trip and with the cumulative number of trips. *Thus, the self-ratings were not very good indicators of drowsiness, but they may have been indicative of increasing stress or compensatory effort that signaled fatigue or loss of alertness.* (pp. 5-11).

Performance tests and fatigue: Drivers performed less well during the night than during the day on a test of mental performance and information-processing speed. They also performed worse at the end of a trip than at the beginning and midpoint. However, drivers' scores improved slightly after their scheduled mid-trip break. The drivers' scores on a test of vigilance and reaction time showed a trend of lowered performance with each added trip in both the 10-hour and the 13-hour conditions. Drivers' performance on a test sensitive to hand-eye coordination did not indicate performance differences between the two types of 10-hour and 13-hour trips. Drivers' self-ratings of mood and alertness (Stanford Sleepiness Scale) had little correlation to their scores on the three performance tests. The drivers tended to rate themselves more alert than their test scores indicated.

Driving performance and fatigue: When adjusted for route-dependent effects (curves, roadway superelevation, pavement condition), steering variability during the 13-hour conditions was greater for periods when drivers were judged drowsy on the basis of video records than for periods when they were not judged drowsy. (The 10-hour conditions were not examined from this perspective due to data limitations). Drowsiness was associated with increased variability in lane tracking.

Sleep and fatigue: Overall, drivers in this study obtained nearly 2 hours less sleep per sleep period than their stated "ideal" (5.2 hours versus 7.2 hours). However, many of them did not manage their off-duty time efficiently or effectively, to obtain sufficient sleep. Commuting, meals, personal hygiene, social interaction, the study protocol, and sleep had to be fit into their off-duty periods.

All the drivers studied obtained efficient, normally-structured sleep as judged by formal clinical criteria. The low amount of time awake after sleep commenced was consistent with reduced time in bed and sleep deprivation. The drivers in the 13-hour midnight-start condition, whose schedules consistently required them to sleep during the day, spent significantly less time in bed per principal sleep period than the drivers in the other three conditions. Of drivers participating in the study, 44 percent stopped and took naps (1-3 per run), increasing their daily sleep time by an average of 27 minutes, or 11 percent over their main sleep period.

Sleep apnea: Although this study was not designed to determine a CMV driver population prevalence of sleep apnea, two of the 80 drivers (2.5 percent) who participated were observed to have clinically-diagnosable sleep apnea. The driving performance of these individuals was not statistically different from that of the other drivers in the study.

The authors believe several of the study's findings are immediately applicable for use in driver education programs for fatigue awareness and prevention: (1) the increased potential for drowsiness and poorer performance during late-night driving, (2) the importance of obtaining enough quality sleep before driving; and (3) the finding that many drivers in the study were poor judges of their own fatigue impairment. The authors believe that CMV drivers can be trained to better assess their condition. They close the report by stating that driver fatigue is a serious concern and that much can be done to address it through education, increased awareness of circadian effects on alertness and performance, improved driver selection and training, development of innovative hours-of-service regulations and enforcement of the regulations, as well as additional research.

Bonnet, M.H. (1994) Sleep Deprivation. In W. Kryger, T. Roth, & W. Dement, W. (Eds.), *Principles and Practices of Sleep Medicine, 2nd edition.* (Chapter 5, pp. 50-67). Philadelphia, PA: W.B. Saunders Company

It is not sufficient to assign a period for sleeping and to assume it will always result in a fully restorative effect. The continuity of the sleep obtained is integral to its quality. According to Bonnet, *Evidence has begun to demonstrate that sleep is a time-based cumulative process, and that frequent awakenings can slow or stop that process in a lawful fashion.* (p. 61)

Bonnet cites studies showing that brief arousals during sleep systematically reduced daytime alertness. The studies found no effects for periods of sleep between arousals longer than 20 minutes, but the effects increased as the intervals were reduced from 20 minutes to 1 minute. Older subjects appeared to be less sensitive to the arousals than younger ones. The researchers believed that very few individuals who did not have a sleep disorder (for example, periodic leg movement or obstructive sleep apnea syndromes) would experience such a high frequency of arousals. Bonnet noted additional potential occasions when sleep fragmentation might occur: when a patient is undergoing treatment in an intensive care unit; in the case of a patient with a chronic pain disorder; and "life requirements" situations involving infant care and training undertaken by medical residents which may also be accompanied by chronic sleep loss. He notes that most of those situations combine chronic partial sleep loss and chronic sleep fragmentation — and the effect of combining those factors is greater than the effect of either one individually.

Roehrs, T., Zorick, F., & Roth, T. (1994). Transient and Short-Term Insomnia. In W. Kryger, T. Roth, and W. Dement, (Eds.) *Principles and Practice of Sleep Medicine, 2nd edition.* (Chapter 46, pp. 486-493). Philadelphia, PA: W.B. Saunders Company.

This book chapter provides an overview of environmentally-related transient insomnia. The authors describe three general categories: unfamiliar sleep environments, nonconductive sleep environments where noise, temperature, sleep surface, or sleep position are factors.

Sensitivity to noise during sleep can vary considerably from one individual to another. Intensity, and informational (cognitive or emotional) value can be important. People may not remember sleep-disrupting noise after they wake, but may complain of generally disturbed sleep or fatigue. Lab studies consistently show disturbed sleep as a result of noise and research has noted a relationships between brief non-awakening arousals and increased daytime sleepiness. On the other hand, some researchers have observed instances of partial, but not complete, noise adaptation.

Temperature sensitivity also varies among individuals, and temperature fluctuations have been shown to lead to disturbed sleep.

Sleep surface is the source of subjective complaints but there have been very few objective studies and they have not demonstrated differences in sleep. The authors state a change in sleep surface may well have a transient effect but they also state that it has not been studied.

Sleep position (posture other than horizontal) has been linked to increased wakefulness and reduced total sleep time. The authors state that potential degree adaptation is unknown and it has not been studied.

Reviewer's Note: This is worthy of note because of the sometimes less-than-optimal sleeping conditions often encountered by over-the-road drivers.

Mitler, M.M., Miller, J.C., Lipsitz, J.J., Walsh, J.K., & Wylie, C.D. (1997). The Sleep of Long-haul Truck Drivers. ***New England Journal of Medicine. 337*****(11), 755-761.**

The authors collected round-the-clock electrophysiological data and both continuous and discrete-period performance data from four groups of 20 male truck drivers from the United States and Canada. The drivers were on revenue-generating runs and drove on one of four schedules: 10-hour regular daytime driving, 10-hour schedules rotating backwards about 2 hours daily, 13-hour late-night-to-morning, and 13-hour late-afternoon-to-night.

Findings, as reported in the author's abstract, were the following: *Drivers averaged 5.18 hours in bed per day and 4.78 hours of electrophysiologically verified sleep per day over the five day study (range, 3.83 hours of sleep for those on the steady 13-hour night schedule to 5.38 hours of sleep for those on the steady 10-hour day schedule). These values compared with a mean (± SD) self-reported ideal amount of sleep of 7.1 ±1 hours a day. For 35 drivers (44 percent), naps augmented the sleep obtained by an average of 0.45 ± 0.31 hour. No crashes or other vehicle mishaps occurred. Two drivers had undiagnosed sleep apnea, as* *detected by polysomnography. Two other drivers had one episode each of stage 1 sleep while driving, as detected by electroencephalography. Forty-five drivers (56 percent) had at least 1 six-minute interval of drowsiness while driving, as judged by analysis of video recordings of their faces; 1067 of the 1989 six-minute segments (54 percent) showing drowsy drivers involved just eight drivers.* (p. 755)

Reviewer's Notes: This paper focuses upon the sleep and sleep-related data collected under the FHWA-Transport Canada-TRI *Driver Fatigue and Alertness Study* (Wylie et al. 1996). The full report also covers driving performance, performance on offline tasks (hand-eye coordination, reaction time, cognitive functioning), and drivers' subjective assessment of alertness state.

Wylie, D. (1998). ***Driver Drowsiness, Length of Prior Principal Sleep Periods, and Naps.*** **(Report No. TP 13237E) Montreal, Quebec: Transportation Development Centre, Safety and Security Group, Transport Canada.**

(Author's Abstract) The purpose of this study was to assess the relationships between the prevalence of driver drowsiness observed on a trip, length of prior principal sleep periods, and naps taken during the trip. The analyses used the data collected from actual revenue runs of the *Driver Fatigue and Alertness Study (DFAS)* and the *Commercial Motor Vehicle Driver Rest Periods and Recovery of Performance Study*. A rhythmic time-of-day variation was the strongest influence found on drowsiness, followed by length of the last main sleep. A mathematical model was developed that describes these effects. It was found that half the naps studied were taken in apparent absence of drowsiness and half appeared to be taken in response to sudden increases in drowsiness. Naps in trips with judged drowsiness appeared to result in a recovery effect compared to the relatively high levels of drowsiness seen in the hour prior to napping. However, drowsiness remained substantially elevated for two hours after napping.

Time-of-day of nap onset favored the early morning hours, peaking at 5:00 a.m. and 6:00 a.m. The time after trip start was far more variable. The assessment of drowsiness indicators for the napping drivers ("drowsy," "droopy lids," and "blinks") were highly correlated, lending additional credence to the use of the overall assessment of "drowsiness."

The indicators appeared to be most visible starting two hours prior to the nap, and continuing to two hours after the nap.

Reviewer's Notes: The numerical model of time-of-day variation in the proportion of drowsy epochs was extended to include the length of last sleep and continued to converge satisfactorily. However, Wylie's analysis found that the addition of that term added very little quantitative value to the model. Ongoing work by Belenky et al. will continue to address this issue.

Hertz, R.P. (1988 February). *Tractor-trailer Driver Fatality: The Role of Nonconsecutive Rest in a Sleeper Berth.* Washington, DC: Insurance Institute for Highway Safety.

Hertz based this study upon an analysis of truck crash reports filed in 1984 with the FHWA. Out of 37,313 records, she selected all tractor-trailer crashes where the truck driver was killed (418 cases) and all reported property damage only cases involving tractor trailers (comparison group of 15,692 cases). She estimated the drivers' use of a sleeper berth for non-consecutive periods from information contained in the accident report, namely the driver's statement on the number of hours driven since the last eight-hour off-duty period. Hertz computed odds ratios of exposure to between the case and comparison groups, subjected them to statistical tests, and placed them in a logistical regression model to adjust for statistical confounds.

Using an adjusted odds ratio, Hertz found a three-fold increase in tractor-trailer driver fatalities when the sleeper berth time was taken in two periods. She attributes this to irregular work and rest schedules and disruption of circadian rhythms, limited length of sleep, and condensing work hours into a shorter period of time.

Sleep Deprivation Countermeasures: Naps

Taking a nap can prevent drowsiness or can be a countermeasure to it. However, naps need to be taken at appropriate times and for appropriate lengths of time. Nappers need to be aware of the potential for sleep inertia following a nap, and to allow sufficient time after waking for it to pass before commencing work requiring alertness.

The following selection of papers describes the ability of human subjects to nap, the quality of sleep obtained during napping, and the use and potential use of naps in operational settings.

Lavie, P., Scherson, A. (1981). Ultra Short Sleep-Waking Schedule. i. Evidence of Ultradian Rhythmicity in 'Sleepability.' ***Electroencephalography and Clinical Neurophysiology. 52*****: 163-174. Elsevier/North Holland Scientific Publishers, Ltd.**

Lavie, P., Zomer, J. (1984). Ultrashort Sleep-Waking Schedule. ii. Relationship Between Ultradian Rhythms in Sleepability and the REM-Non-REM Cycles and Effects of the Circadian Phase. ***Electroencephalography and Clinical Neurophysiology. 57*****, 35-42. Elsevier/North Holland Scientific Publishers, Ltd.**

Lavie, P. (1986). Ultrashort Sleep-Waking Schedule. iii. 'Gates' and 'Forbidden Zones' for Sleep. ***Electroencephalography and Clinical Neurophysiology, 63*****: 414-425. Elsevier/North Holland Scientific Publishers, Ltd.**

The purpose of these three laboratory studies was to determine whether and how the propensity to sleep was influenced by circadianrhythms, prior Rapid Eye Movement (REM) sleep stage deprivation, and prior sleep deprivation. The research subjects were healthy young adults with no reported sleep problems who were placed on various "ultra short" schedules (15 minutes awake and five minutes sleeping in first two studies; 13 minutes awake and seven minutes sleeping in the third).

In the first study, these ultra short periods began in the mid-morning. In the second, they began in the afternoon. In the last, the subjects al underwent a night of sleep deprivation and began their ultra short periods in the early morning, late morning, or early evening. Sleep was monitored via electroencephalographic (EEG) recording in each study. In the third study, the subjects also performed reaction-time tasks.

In the first study, Lavie and his colleagues found a rhythm in the amount of Stage 1 sleep of about 14.4 cycles per day (period of 100 minutes) but no rhythmicity in Stage 2 sleep after subjects had seven to eight hours of continuous nocturnal sleep. After a night of total sleep deprivation, a bimodal distribution was noted for Stage 2 sleep but the rhythm for Stage 1 sleep was disrupted.

The second study found an ultradian frequency of about 7.2 cycles per day tied to sleep onset but additional spectral analysis that synchronized morning time-series with the prior nocturnal REM period produced a 14.4 cycle/day pattern.

The third study detected a bimodal distribution of sleepiness 'peaks,' a very high degree of stability in the time when subjects commenced their nocturnal sleep and what the author termed a "forbidden zone" nadir in sleep propensity beginning from four to two hours before the commencement of a "sleep gate" [onset of a nocturnal sleep period].

Reviewer's Notes: These three studies, particularly the last, highlight the complex biological nature of sleep. They also help to explain the difficulty that many of us have in altering our accustomed sleep-wake patterns.

P. Lavie (1989). To Nap, Perchance to Sleep — Ultradian Aspects of Napping. In D. Dinges and R. Broughton, (Eds.) *Sleep and Alertness, Chronobiological, Behavioral, and Medical Aspects of Napping.* (Chapter 6) New York: Raven Press.

The following chapter of this book summarizes several findings from Lavie's and others' research on nap timing and sleep quality and quantity.

Concerning naps and sleep inertia: *Whether afternoon or evening naps will contain REM sleep in persons who have normal nocturnal sleep depends upon the length of the nap . . .* (p. 179) It does not occur in otherwise healthy persons if the nap is 30 minutes long; it may occur in a one-hour nap; and it is very likely in a nap of two hours or longer. Lavie cites studies indicating even when REM does appear it rarely occurs before 50 minutes after sleep onset.

Concerning nap efficiency: nocturnal sleep efficiency (total sleep time / time in bed) is nearly always more than 80 percent and often more than 90 percent. By contrast, nap sleep efficiency at any time of day is rarely more than 80 percent. Sleep efficiency for 1-hour afternoon or evening naps is typically between 55 percent and 70 percent.

Concerning nap times: Lavie cites Dinges' and colleagues studies of college students indicated two four-to-five hour time periods: nocturnal zone 11:00 p.m. to 4:00 a.m., containing 85 percent of nappers' sleep onsets, and nap zone 2:00 p.m. to 6:00 p.m., containing 15 percent of the sleep onsets. Dinges et al. also found that naps were as likely to be taken on weekends as during the week. This was unexpected because it had been assumed the students would have napped less on weekends.

Caldwell, J.A., Jones, R.W., Caldwell, J.L., Colon, J.A., Pegues, A., Iverson, L., Roberts, K.A., Ramspott, S., Sprenger, W.D., & Gardner, S.J. (1997) *The Efficacy of Hypnotic-Induced Prophylactic Naps for the Maintenance of Alertness and Performance in Sustained Operations*. (Report No. 97-10). Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory.

This was a laboratory study of 18 Army aviators and flight students. The authors compared two-hour prophylactic [i.e., of a preventive nature] naps, natural or induced with zolpidem tartarate, with no-nap forced rest periods provided during a period of extended wakefulness simulating a 38-hour continuous operation. The researchers noted improvements in napping subjects' self-ratings and in EEG indications of central nervous system arousal. Although they noted that cognitive performance was often, but not always, impaired by sleep deprivation, the researchers found their subjects performed better on a subset of the tasks after napping than after rest only. The researchers found evidence of sleep inertia up to three hours following naps.

Dinges, D.F. (1989) Napping Patterns and Effects in Human Adults. In D.F. Dinges & R.J. Broughton (Eds.), *Sleep and Alertness: Chronobiological, Behavioral, and Medical Aspects of Napping*. pp. 171-200. New York: Raven Press.

This book chapter focuses on post-nap sleep inertia. Dinges states that post-nap sleep inertia is ubiquitous. It is of relatively brief duration (5 - 15 minutes) in subjects who are not sleep-deprived but it can last longer and be more severe if the nap sleep follows a protracted period of wakefulness. He considered sleep inertia to produce potential negative self-reports of mood and behavior but these are of short duration. Dinges also believed this might not be a significant factor in non-nappers decisions not to nap, and notes: *There is little evidence that sleep inertia is even the basis for complaints of the small minority of non-nappers who report unpleasant mental and physical aftereffects of naps,* because the subjects reported those aftereffects long after sleep inertia dissipated. (p. 196)

On the other hand, if a subject has to perform at a high level immediately after awakening, sleep inertia can be a major concern. Performance effects shortly after napping have been mixed. Some researchers have reported statistically significant improvements on reaction-time tasks; others have not observed physiologically-measured improvements. However, Dinges and other researchers have noted performance improvements several hours after a nap, and suggested the nap "prophylactically prevented some of the performance deterioration that typically results from sustained wakefulness." (p. 198)

Duffy, J.F., Kronauer, R.E., & Czeisler, C.A. (1996). Phase-Shifting Human Circadian Rhythms: Influence of Sleep Timing, Social Contact and Light Exposure. *Journal of Physiology 495 (1)* 289-297.

This was a laboratory study to determine the contributions of behavior (activity, sleep, social interaction) and environment (light and darkness) upon human entrainment to the 24-hour day.

The researchers subjected 32 young male subjects to an inverted schedule [i.e., waking periods at night and sleep periods during the day] in an environment free of time cues. The exposure to light was controlled and provided ambient room illumination of 10-15 lux and bright light of approximately 10,000 lux.

After a 10-day period, the subjects who were exposed to the bright light exhibited a phase shift to the new schedule as determined by changes in core body temperature cycles. The group of subjects who were not exposed to bright light did not exhibit this phase shift.

The authors suggest that the results support the role of the light-dark cycle as a circadian synchronizer and the minimal influence of a schedule shift acting alone.

Sallinen, M., Härmä, M., Åkerstedt, T., Rosa, R., & Lillqvist O. (1997 November). Can a Short Napbreak Improve Alertness in a Night Shift? ***Shiftwork International Newsletter 14*** **(2) p. 25.**

This was an initial summary report of a laboratory study of 14 experienced male shiftworkers, ages 31-52. The workers participated in five non-consecutive experimental night shifts. There were five conditions: nap breaks of 50 or 30 minutes, starting at either 1:00 a.m. or 4:00 a.m., and a control of no nap break. The workers had a day sleep of at least 5.5 hours. The researchers assessed the workers' performance, subjective sleepiness, and physiological sleepiness.

The researchers found that performance, specifically lowered lapsing on a reaction-time test, was most influenced by a nap break of less than one hour. It did not appear to matter if the nap was taken early or late. They also found only small differences in subjective sleep quality data between nap and no-nap conditions. They noted that sleep inertia effects lasted about 10 minutes, and that it must be taken into account if naps are implemented into work operations.

Hours-of-Service Regulations: General Considerations

This section summarizes several reports and papers dealing with general considerations concerning the role of operator drowsiness and loss-of-alertness as contributors to transportation accidents and incidents. Various writers describe how knowledge of scheduling practices and human performance characteristics and limitations can mitigate and prevent adverse outcomes in a society dependent upon safe, economical, and dependable 24-hour transportation operations.

U.S. Congress Office of Technology Assessment (1988). ***Gearing Up for Safety: Motor Carrier Safety in a Competitive Environment.*** **Washington, DC: U.S. Government Printing Office.**

The report cites contemporary [circa mid-1980s] United States and overseas research concerning CMV driver fatigue and hours-of-service. It emphasizes the need to better understand influence of circadian rhythms and fatigue. *[The Office of Technology Assessment] OTA concludes that aggressive Federal research programs to address fatigue and sleep issues and to determine their role in truck accidents are top priorities ... OTA research points to compelling reasons for DOT to reexamine the hours-of-service regulations, and to develop revised standards based on current knowledge of the around-the-clock operating environment necessary today.* (p. 13)

Concerning countermeasures and crash prevention, the report contends: *Federal support for research on fatigue could also provide information to help management and drivers understand when drivers are most vulnerable to accidents and how scheduling and procedures might be altered to accommodate sleep needs.* (p. 13)

Reviewer's Notes: The publication of this report was one of several activities that brought CMV operator fatigue and loss-of-alertness back into the spotlight after several years of relatively low levels of DOT activity following the 1981 withdrawal of proposed changes to the hours-of-service regulations.

Mitler, M.M., Carskadon, M.A., Czeisler, C.A., Dement, W.C., Dinges, D.F., & Graeber, R.C. (1988). Catastrophes, Sleep, and Public Policy: Consensus Report. *Sleep 11(1)* 100-109.

This paper reports the findings and recommendations of a committee of scientists formed following the 1986 annual meeting of the Association of Professional Sleep Societies.

The report opens with an overview of contemporary research on relationships between the biological clock and human sleepiness and sleep vulnerability. The authors note the early-morning and late-afternoon periods when the propensity to sleep is highest. After citing other studies of temporal distributions of mortality and heart attacks, the focus turns to the temporal distribution of single-vehicle highway accidents (such as run-off-road) because of the authors' belief that this type of accident has a higher probability of being related to drivers' unintentional attention lapses. The accident studies evaluated included automobile and heavy vehicles taking place in United States and overseas. Finally, the authors review studies of temporal trends observed in studies of operator performance errors and in major disasters (the *Challenger* Accident and Three Mile Island).

The authors made a series of recommendations, including:

- A need to increase the awareness of policymakers and regulatory agencies of the potential for greatly increased chances for medical and performance catastrophes between 1:00 a.m. and 8:00 a.m. and 2:00 p.m. to 6:00 p.m.;
- A need to develop programs to identify signs of sleep-related error in the workplace especially when public health and safety consequences are significant; ". . . inadequate sleep, even as little as 1 or 2 hours less than usual sleep, can greatly exaggerate the tendency for error during the time zones of vulnerability" (p. 107).
- A need to address the physiological requirements of workers and the safety requirements of society and the development of schedules that promote health and safety with minimal expense;
- A need to perform laboratory and field research into the fundamentals of bimodal temporal patterns of human physiology and performance, and development of effective countermeasures to minimize adverse consequences of operators and decisionmakers engaged in around-the-clock operations.

Reviewer's Notes: This is one of the most often cited "early" issue papers on the relationships between combined time-of-day and sleep-loss effects and severe performance decrements, accidents, and industrial disasters.

McDonald, N. (1989). Professional Driving Safety — Fatigue, Stress, and the Design of Countermeasures (summary of discussions). In P. Hamelin (Ed.), *Working Conditions of Drivers in Road Transport.* pp 23-26. (Actes INRETS Publication No. 23) Arcuiel, France, Commission of European Communities Discussion Group conducted at the Institut National de Recherche sur les Transports et leur Securite.

In his paper, McDonald asserts that placing a regulatory emphasis on hours and duration of driving or work may be simplistic because there are different patterns but no single linear increase in accident risk. He suggests viewing fatigue as an impairment with a criterion related to marked divergence from normal pattern of activity. He adds that one of the challenges of studying fatigue is assessing external stresses and how people respond in a given situation.

Reviewer's Notes: The papers from this Discussion Group provide an overview of working conditions of long-distance transport drivers in Europe. It covers topics similar to those discussed in the United States reports described earlier but from the points of view of European scientists.

Åkerstedt, T., & Folkard, S. (1989). Sleepiness at Work: Measurement and Regulation (discussion abstract). In P. Hamelin (Ed.), *Working Conditions of Drivers in Road Transport.* pp. 67-71. (Publication Actes INRETS No. 23) Arcuiel, France, Commission of European Communities Discussion Group conducted at the Institut National de Recherche sur les Transports et leur Securite.

This paper from the same conference cites field research results that point to a physiological basis for driver fatigue: EEG recordings indicate increased alpha waves and slow-eye movement (SEM) activity during the early-morning portion of night work. The authors state: *We estimate that at least 25 percent of the night working population severely suffers from such sleepiness with irresistible attacks of sleep, and that a further 50 percent suffers from increased sleepiness without sleep attacks . . . Experimental evidence supported by field* *studies indicate that the major determinants of sleepiness are time awake (amount of sleep) and time of day . . .* (p. 67)

Åkerstedt, T. (1991). Sleepiness at Work: Effects of Irregular Wake Hours. In T. Monk (Ed.) *Sleep, Sleepiness, and Performance.* (Pp. 129-152) Chichester, England: John Wiley & Sons, Ltd.

The author highlights the association of irregular work hours with increased subjective, behavioral, and physiological sleepiness. He states these effects appear to be the most pronounced during a night shift, least during an afternoon shift, and an intermediate level in morning shifts.

Åkerstedt notes the presence of physiological, subjective, and performance changes in sleepy people. Physiological changes included slow eye movements and EEG activity indicative of sleepiness, even in situations where no sleep periods over 5 seconds were observed. In addition, some research subjects performed in a semi-automatic activity mode while they were falling asleep. In one study the co-author conducted, the participants' had consistent subjective ratings of being sleepy shortly (plus or minus one-half hour) before the actual event, but they said they did not have a final premonition of their imminent dozing-off although they recalled struggling to stay awake.

Åkerstedt discusses the issue of shortened daytime sleeps. He notes the strong relationship between circadian rhythms and sleep duration and the severe truncation of sleep in the morning hours. However, the homeostatic need for recuperative sleep after a shorter-than-usual sleep period is also an influence.

The author compares various outcomes related to shift work. He noted mixed results when the length of shifts was the focus of comparison (8 or 12 hours). The workers on the 12-hour shifts experienced more subjective fatigue but they had four days off at the end of the work cycle and expressed strong preference for that feature. Various other outcome ratings were mixed (index of well-being, general health), but some researchers whose work was cited noted increased sleep problems in patients referred to sleep clinics and increased incidence of myocardial infarcts and cardiovascular disease in general.

Åkerstedt, T. (1995). Work Hours, Sleepiness, and the Underlying Mechanisms. *Journal of Sleep Research 4* (Supp. 2) 15-22.

The author describes how work hours can conflict with basic biological regulation of rest and activity. He notes three outcomes: shortened sleep, an unfavorable time of day when work is to be performed, and an extended period awake. As he states in his abstract: *The alertness deficit is caused by the displacement of work to the circadian phase which is least conducive to alert behavior, by extension of the time spent awake and by the reduction of sleep length (due to circadian interference with sleep). Sleepiness will be extreme when the three cases are operative simultaneously.* (p. 15)

Åkerstedt views shortened sleep during the morning following night work as indicative of a circadian influence: the length of sleep time will vary according to the time it commences. A bedtime commencing at 11:00 p.m. hours might last eight to nine hours; if the sleep time is delayed to the early morning, the sleep time drops to four to four and one-half hours. By that midafternoon to early evening, the sleep period rises again. Another influence upon shorter daytime sleep periods is the length of a prior sleep period. A nap taken during the night would shrink the sleep period taken the following day. There is also an early-evening period where people are highly resistant to sleep: Åkerstedt cites Lavie's term, "forbidden zone." [See earlier discussion in this document of Lavie's papers on the subject.]

Åkerstedt models alertness levels using 3 parameters: C, circadian influences; S, an exponential function of time since awakening; and W, the wakeup process or sleep inertia after forced awakenings.

Manber, R., Bootzin, R., Acebo, C., & Carskadon, M. (1996). The Effects of Regularizing Sleep-Wake Schedules on Daytime Sleepiness. *Sleep 19* (5), 432-441.

This study evaluated the effects of two variations of a sleep schedule on subjective daytime alertness. The subjects were undergraduate college students.

After a 12-day baseline period, all subjects were requested to take at least 7.5 hours of sleep, to expose themselves to daylight upon awakening, to keep their caffeine intake to baseline levels, and to avoid daytime napping. One experimental group was instructed to take the sleep; the other group was instructed to maintain a regular schedule by going to bed and waking up during 1-hour time blocks assigned to them based upon their habitual sleep-wake schedules recorded in diaries and in consultation with the research team. The experimental period lasted 4 weeks. A follow-up period began 5 weeks after the experimental period ended. Subjects recorded self-assessments and data via daily diary entries and also phoned in their data during the experiment.

According to the authors, *The combination of adequate sleep duration and regular nocturnal sleep schedules was found in the present study to be superior to adequate sleep duration alone in decreasing reported sleepiness and improving sleep efficiency. Even though there was an overall significant reduction in reported daytime sleepiness for all subjects, subjects in the regularity group reported greater and longer-lasting improvements in daytime sleepiness. This improvement was observed despite the fact that during the 4 weeks of the experimental phase, subjects in the regularity group slept about half an hour less per 24-hour period compared to subjects in the sleep only group.* (p. 439)

The authors found that, as they had expected, levels of daytime sleepiness were significantly tied to prior nighttime sleep. The authors also noted their results were consistent with Åkerstedt, who reported negative effects on sleep efficiency from irregular sleep schedules. They noted their results were not consistent with research by Bonnet and Alter who did not note changes in objective (via EEG) changes in sleep latency or sleep efficiency from regularizing a sleep schedule; they speculated that the subjects might have needed additional time, beyond the completion of the experiment, to complete their adjustment to a regular sleep schedule. The authors also addressed the importance of providing specific instructions. In a previous study, the authors had required their student subjects to wake at a regular time but they did not explicitly require them to go to sleep at a regular time. The students became chronically sleep deprived and showed increased daytime sleepiness.

The OMCS is not alone among transportation safety agencies in gathering research and operational information to form foundations for considering potential changes to hours-of-service regulations, legislation, or operating practices. The following summaries describe elements of contemporary research studies relating to operator schedules and work and sleep cycles in the marine, rail, and aviation environments.

Sanquist, T.F., Raby, M., Maloney, A.L., & Carvalhais, A.B. (1996). ***Fatigue and Alertness in Merchant Marine Personnel: A Field Study of Work and Sleep Patterns.*** **(Report No. CG-D-06-97). Washington, DC: U.S. Coast Guard.**

This study was conducted to quantify the nature and extent of fatigue in mariners. Data in work and sleep logs was collected for periods from 10 to 30 days from 141 mariners on eight different ships involved in U.S. west coast trade. Among the findings: average sleep duration at home was 7.9 hours while average sleep duration at sea was 6.8 hours; watchstanders slept less time and rated their sleep to be of lower quality compared to command personnel or day-workers; and the workdays of watchstanders are longer than for command and day-work personnel. The researchers also analyzed what they termed "critical fatigue indicators," the proportion of 24-hour periods during which total sleep was less than four hours, the proportion of alertness self-assessments of 3 or lower recorded in the sleep log, and the proportion of sleep latencies (time between going to bed and falling asleep) of five minutes or less as recorded in the sleep log. Watchstanders fared worse than command or daywork personnel, and watchstanders on the 4:00 a.m. to 8:00 a.m. watch had a considerably higher incidence of sleep durations under 4 hours in a 24-hour period. The report concluded: *The data clearly portray that risk factors for fatigue are present in maritime work schedules. The solution to this problem involves providing the opportunity for a longer continuous rest period, and motivating mariners to take advantage of that rest period for a single, uninterrupted sleep. A review of shipboard operational practices may identify various means to provide longer continuous rest periods and other approaches to fatigue reduction.* (p. 6)

U.S. Coast Guard (March 1997). ***Procedures for Investigating and Reporting Human Factors and Fatigue Contributions to Maritime Casualties.*** **(Report MSC 68/INF/) Report submitted to the Marine Safety Committee, International Maritime Organization. Washington, DC: U.S. Coast Guard**

The U.S. Coast Guard developed a "Fatigue Index" score for cases involving critical vessel and personnel casualties where there was significant property damage, the loss of the vessel, or personnel injury. The index score was based upon the number of fatigue symptoms reported by the mariner, the number of hours worked in the 24 hours prior to the casualty, and the number of hours slept in the 24 hours prior to the casualty. When the index procedure was applied to 279 critical vessel and personnel casualty cases, fatigue was estimated to have contributed to 16 percent of the critical vessel casualties and 33 percent of the personnel injury casualties. These estimates are considerably higher than the 1.2 percent and 1.3 percent estimates derived from a 1993 U.S. Coast Guard Marine Investigation Module data analysis. The Coast Guard stated it would apply fatigue investigation and reporting procedures to all critical vessel and personnel casualties investigated by the Coast Guard for a one-year period to identify industry segments in need of attention to reduce fatigue-related casualties and to support identification of working conditions that contribute to these casualties.

Buck, L., Greenley, M., Loughnane, D., & Webb, L. (December 1995). Statutory Hours of Work for Marine Watchkeepers. *Shiftwork International Newsletter 12*(1), p. 68.

This abstract reviewed existing Canadian Safe Manning Regulations promulgated in 1978. According to the authors, *The current regulations govern only hours of rest, they do not regulate hours of work nor duty scheduling ... in particular, they do not address questions relating to the time of day at which work was done and rest was taken. Furthermore, they regulate hours of rest, not hours of sleep.* (p. 68)

The authors recommended several changes: changing the title of the regulation from "Hours of Rest" to "Duty Schedule;" requiring a 24-hour schedule to be published at the beginning of every voyage; specify criteria to design a duty schedule; limit hours of duty to 18 hours in one day and 24 hours in two successive days; require 6 hours rest in one day and 24 hours in two consecutive days.

Thomas, G.R., Raslear, T.G., & Kuehn, G.I. (1997) *The Effects of Work Schedule on Train Handling Performance and Sleep of Locomotive Engineers: A Simulator Study.* Report DOT/FRA/ORD-97-09. Washington, DC: Federal Railroad Administration.

This study compared two schedules, one involving a fast-backward rotation, the other, a slow-backward rotation. The study participants received a crew call two hours prior to going on duty, as they would under their normal operational protocol. Under the fast-rotating schedule, the engineers' sleep duration averaged 4.6 hours during a 9.3 consecutive hour off-duty period. Under the slow-rotating schedule, the average sleep duration was 6.1 hours during a 12 consecutive hour off-duty period. (The minimum off-duty time required was 8 consecutive hours if the engineer had less than 12 hours on duty.)

Moore-Ede, M., Mitchell, R.E., Heitmann, A., Trutschel, U., Aguirre, A., & Hajarnavis, H. (May 1996) *CANALERT '95 – Alertness Assurance in the Canadian Railways.* Appendices C, D, E, F. Cambridge, MA: Circadian Technologies, Inc.

The following information is drawn from Questions 67 through 70 of the Stage II Volunteer Survey, Overall Totals. Locomotive engineers participating in the survey were asked several questions concerning sleep needs and sleep obtained. To "feel alert and well rested," 10.8 percent stated they needed fewer than 5 hours or 5 hours; 35.1 percent, 6 hours of sleep; 29.7 percent, 7 hours; 24.3 percent, 8 or more hours. On average, the engineers said the sleep they actually got on days they worked averaged: fewer than 5 hours, 21.6 percent; 5 hours, 16.2 percent; 6 hours, 21.6 percent; 7 hours, 29.7 percent; and 8 or more hours, 10.8 percent. On days off, the engineers stated they received: 7 hours, 37.8 percent; 8 or more hours, 43.2 percent; all other amounts 6 hours or less, 18.9 percent. During vacations, sleep times averaged: 35.1 percent, 7 hours; 51.4 percent, 8 or more hours; all other amounts 6 hours or less, 13.5 percent.

Hildebrandt, G., Rohmert, W., & Rutenfranz, J. (1974). 12 & 24 H Rhythms in Error Frequency of Locomotive Drivers and the Influence of Tiredness. *International Journal of Chronobiology 2*, 175-180. London: John Wiley & Sons, Ltd.

Railroad locomotives are equipped with passive warning devices, such as deadman switches used in the United States, that require the engineer to respond to their signals. If the engineer does not respond to a lighted lamp within a specified time period, a second, acoustic, signal may be activated. If the engineer still does not respond, the train's brakes are automatically activated.

This study assessed the relative frequency of the second signals and of the occurrence of automatic braking by time of day and by length of shift. The researchers reviewed one month's records covering approximately 15,000 locomotive engineers employed by the German Federal Railways. The records covered 2,238 automatic braking incidents and nearly 20,000 second-level warning signals.

The researchers found peaks of about 125 percent of the daily average automatic braking incidents taking place around 3:00 a.m. and 1:00 p.m. - 2:00 p.m. They found peaks in the activation of the acoustic signal at around 3:00 a.m. and 3:00 p.m. The authors believed that daylight probably increased the difficulty of seeing the initial signal and the relative variability of the sounding of the audible alarm did indeed show peaks between 2:00 a.m. and 3:00 a.m. However, they also assessed the mean hourly frequency of these early-afternoon alarms according to the time the engineers began their shifts. Those engineers who were in the 4^{th} through 6^{th} hour of their shifts during the afternoon or night peaks experienced the highest frequencies of audible alarms. The authors concluded there exists a 12-hour period of variation in vigilance, superposed upon the 24-hour circadian period.

Gander, P.H., Graeber, R.C., Connell, L.J., & Gregory, K.B. (December 1991) ***Crew Factors in Flight Operations: VIII. Factors Influencing Sleep Timing and Subjective Sleep Quality in Commercial Long-Haul Flight Crews.*** **(NASA Technical Memorandum 103852.) Washington, DC: NASA.**

This study was performed to document how commercial flight crews organize their sleep during layovers on long-haul (trans-oceanic) trips involving crossing of multiple time zones. Duty periods in the trips studied averaged 10.3 hours. The duty periods alternated with layovers averaging 24.8 hours, and the crew members typically took their sleep in two periods. The authors noted that the sleep/wake patterns were complex, with an average pattern of sleep and wakefulness of 19 hours wake/5.7 hours sleep/7.4 hours wake/5.8 hours sleep. The flight crews also reported naps on the flightdeck and during the off-duty periods. The authors stated: *This study clearly documents that, in scheduled commercial long-haul operations, there are physiologically and environmentally determined preferred sleep times within a layover. The actual time available for sleep is thus less than the scheduled rest period."* (p. 1)

Federal Aviation Administration (1995). ***Notice of Proposed Rulemaking, Flight Crewmember Duty Period Limitation, Flight Time Limitations and Rest Requirements.*** **60 FR 65951, December 20, 1995.**

Federal Aviation Administration (1999). ***Notice of Enforcement Policy; Flight Crewmember Flight Time Limitations and Rest Requirements.*** **64 FR 32176, June 15, 1999.**

The Aviation Rulemaking Advisory Committee (ARAC) Flight/Duty Working Group recommended the FAA address four major issues in future rulemaking: absence of a duty-time limitation, scheduling of reserve (non-scheduled flight) time, back-side-of-the-clock operations (scheduled operations during crewmember's normal sleep cycle), and scheduled reduced rest periods.

The FAA reported that the Working Group did not reach consensus, and proposals were submitted by several of its members. The Working Group's report stated there was sufficient scientific guidance available for the FAA to establish a regulatory "safety floor" that would address the issues of concern and not unfairly penalize air carriers economically. The report also stated there was no physiological justification for different work rules for part 121 (domestic, flag, supplemental) and part 135 (commuter) air carriers.

The main elements of the proposed rules (for flights with 1 or 2 pilots) include a duty period of no more than 14 hours; flight time no more than 8 hours; and a minimum rest period of 10 hours. The minimum rest period may be reduced to 9 hours if the duty period has not exceeded 14 hours, but the next "compensatory" rest period must be at least 11 hours. An extended duty period of up to 16 hours would be permitted only if it is due to operational delays.

Reviewer's Note: On June 15, 1999 (64 FR 32176) the FAA published a notice of enforcement policy to reiterate its current regulations and regulatory interpretations concerning flight time limitations and rest requirements for domestic operations. Under the current regulations, the minimum scheduled or reduced rest period is 8 hours but the next rest period that must begin no later than 24 hours after the commencement of the reduced rest period, must be one hour longer than it would have been otherwise.

Finally, there are developments concerning potential revisions to hours-of-service regulations in Europe.

Council Regulation (EEC) 3820/85 (1985) as of 20 December 1985 on the Harmonization of Certain Social Legislation Relating to Road Transport. *Official Journal of the European Communities.* Brussels, Belgium.

These regulations apply to highway transportation within the European Community. They cover freight transportation in vehicles 3.5 tonnes (7,700 pounds) or over and passenger transportation in vehicles carrying 10 or more persons including the driver. Regular-route passenger transportation, where the route does not exceed 50 km (31.25 miles), is not subject to the regulations.

The regulations exclude 13 classes of vehicles and services (Article 4 of the regulation, p. L 370/3). Some of these are similar to operations in the United States that are exempt from the Federal Motor Carrier Safety Regulations, such as public emergency services. Some others are not, such as communications utilities and certain agricultural operations. [It is important to note some of these operations involve government-sponsored or government-operated cooperatives.]

Duty hours provisions are as follows:

- Driving time: maximum 9 hours of driving between two daily rest periods. The driving period may be extended to 10 hours up to two times per week; the fortnightly maximum driving limit is 90 hours.
- Breaks: 45 minutes after 4.5 hours of driving or multiple breaks of at least 15 minutes duration. For regular passenger services, drivers may take 30 minute breaks after 4 hours of driving.
- Daily rest: minimum of 11 consecutive hours; may reduce to 9 hours three times per week, must make up lost hours before end of following week.
- Split rest time: may take two or three sleep periods, one must be 8 hours; and the periods must total 12 hours.
- Special provisions for team drivers: minimum 8 consecutive hours rest per driver in a 30-hour period.

- Weekly rest: required after 6 daily driving periods; for international passenger transport other than scheduled services, required after up to 12 daily driving periods.

The minimum weekly rest period is 45 consecutive hours. This may be reduced to 36 hours if it takes place where the driver and vehicle are based. If the driver and vehicle are away from the home base, the period may be reduced to 24 hours. However, if the weekly rest period is reduced, the time must be made up (i.e., returned to the driver) by the end of the following third week. Special provisions are provided for passenger transportation.

Reviewer's Notes: These regulations have not addressed non-driving time. However, a Council of the European Union document, "Proposal for a Council Directive Concerning the Organisation of Working Time for Mobile Workers Performing Road Transport Activities and for Self-Employed Drivers," *(Official Journal of the European Communities*, February 17, 1999), addresses maximum weekly working time (average not to exceed 48 hours); minimum daily rest periods (uninterrupted period of at least 11 hours, time may be reduced to 10 hours if another rest period is extended to 12 hours); and an extended weekly rest period (daily rest period plus another 24 consecutive hours). The proposal also addresses daily working time for night workers, allowable deviations from the Directive by European Union member countries, and recordkeeping requirements.

International Labor Organization Inland Transport Committee (1992). *Recent Developments in Inland Transport.* Twelfth Session, Report I, Geneva.

Chapter 5 of this report provides a comparison of occupational safety and health trends in industrialized and developing countries. The chapter covers diverse topics including accidents, occupational injuries and illnesses, employment conditions, and worker compensation. The summary here concentrates on the section, "Hours of work and safety."

The report cites Nicholas McDonald who notes that, except for in the United States, legislative authorities have rarely conducted research into safety implications of hours-of-service before the regulations were promulgated. The authors of this report believe that economic consideration prevailed, even during the recent process of harmonizing work-hour regulations for international road transportation. They note that the EEC regulations could permit 56 hours of driving time in a 60-65 hour workweek and still comply with the 90-hour fortnightly driving limit.

The authors provide general trend information on roadway accidents: twice as many crashes occur during the second half of trip, and twice as many crashes occur at nighttime compared to daytime especially where driver fatigue is involved. They note an apparent additional risk factor associated with early-morning shifts, noting that shift arrangements are not addressed in the international regulations. They also report working weeks of 60-67 hours and 12-hour days with 8 or more driving hours are common.

The authors state that "Drivers generally do not observe hours of work regulations" and cite data from a 1986 survey indicating over 80 percent of drivers violated EEC regulations. They note that hours of work are higher in the for-hire segment of the industry and that enforcement is a major problem in all countries.

Hours-of-service regulations, working conditions, and regulatory compliance

The studies cited in the following four sections deal with various relationships among hours-of-service regulations, working conditions, and regulatory compliance. The five studies in the first group were surveys of American, Australian, and European CMV operators. The two studies in the second group were drawn from surveys of motor carrier operations and managers. The three studies in the third group were surveys focusing on CMV drivers' opinions of hours-of-service regulations and their conformity to and resistance of various elements of the regulations.

Driver fatigue and working conditions: CMV driver surveys

Several recent general surveys and studies address driver fatigue and working conditions.

McCartt, A.T., Hammer, M.C., Fuller, S.Z., Kosa, M., & Merkerka, Y. (1995). ***Study of Fatigue-Related Driving Among Long-distance Truck Drivers in New York State: Volume 1, Survey of Long-distance Truck Drivers.*** **Albany, NY: State University of New York, Institute of Traffic Safety Management and Research.**

This portion of the two-volume study was comprised of interview results held with 593 long-distance truck drivers. To be included in the survey, the researchers required that the drivers had at least six months experience driving tractor-trailer, made overnight trips, and drove at least 50,000 miles per year for work. Of the prticipating drivers, 87.6 percent drove more than 85,000 miles per year, and 61.3 percent drove more than 100,000 miles per year.

The researchers asked about daily and multiday patterns of driving and working hours. The responses indicated long driving hours (just over one-third of the drivers said they drove more than 60 in a typical 7-day week), long working hours (just over one-third of drivers worked more than 70 hours in a typical 7-day week), multiday trips (nearly 80 percent had trips of 4 or more days duration), irregular work schedules (just over 70 percent), driving between midnight and dawn hours (nearly 80 percent), and delivery schedules that could always, often, or sometimes not be made without speeding or violating hours-of-service regulations (36 percent). Just over one-fifth of the drivers reported one or more crashes over the past 5 years; 7 percent of these drivers indicated drowsiness or falling asleep at the wheel was part of the cause. The authors indicated factors associated with drowsy driving and falling asleep at the wheel included: more frequently having a tight delivery schedule, an irregular work/rest schedule, a driving schedule that included evening or nighttime driving, a greater level of daytime sleepiness as measured by the Epworth Sleepiness Scale,[3] and a greater frequency of violating the hours of service regulations (more than 10 consecutive hours of driving, fewer than 8 hours off-duty, driving more than recorded in record of duty status).

Drivers responses concerning their attitudes to the current hours-of-service regulations were nearly evenly divided: 51.1 percent believed the regulations primarily serve to interfere with their doing their job, and 48.9 percent believed the regulations primarily serve to help protect their safety.

The fatigue countermeasures favored by more than half the surveyed drivers included requiring realistic shipping schedules (90.5 percent), teaching drivers to recognize signs of dangerous levels of drowsiness (84.8 percent), providing scheduling information in advance so they can plan their off-duty time(82.3 percent), adopting a weekly hours-of-service restart rule (76.5 percent), requiring rest breaks after a certain number of hours (61.9 percent), allowing more than 10 hours of driving daily without exceeding the current weekly [on-duty time] maximum (61.3 percent), and penalizing the motor carrier and the driver for hours-of-service violations (60.2 percent).

Countermeasures favored by fewer than half the drivers included: hourly pay (45.7 percent), a 12/12 duty/off-duty schedule (34.3 percent), requiring the use of on-board computers to record driving time (28.9 percent), replacing prescriptive hours-of-service

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[3] *Using that scale, participants rate their likelihood of falling asleep in 8 situations, some known to be very conducive to sleep ("lying down to rest in the afternoon when circumstances permit") and others less so ("sitting and talking to someone") on a 4-point scale. Scores range from 0 to 24; the higher the score, the higher likelihood of dozing in all situations.*

regulations with alertness/performance tests (26.6 percent), requiring more than 8 hours off-duty (23.1 percent), and limiting driving during the middle of the night (16.8 percent).

Arnold, P., Hartley, E.R., Penna, F., Hochstadt, D., Corry, A., & Feyer, A. (1996). ***Fatigue in the Western Australian Transport Industry, Part Two: the Drivers' Perspective.*** **Western Australia: Murdoch University.**

This is the second report in a three-part series. The objectives of the research are to examine fatigue management practices in Western Australia (WA), effectiveness of the approaches, their relationship to national approaches, and how research studies support or refute WA approaches.

The research findings in this report were based upon 726 structured interviews with WA drivers (58 percent response rate) in 6 locations. With few exceptions, researchers reported results with 99 percent or higher confidence interval (chi square).

The following are selected key results summarized by the reviewer:

- Accidents and fatigue-related events during prior 9 months: 3 percent of the drivers reported nodding off often or very frequently, 5.8 percent reported having a near-miss often or very frequently. The authors believe this is an underestimate, noting differences in drivers' responses to questions concerning their experiences in the current trip and within the past nine months.

- Hazardous events and operating conditions (route-dependence observed): hazardous events and drivers' hours (drivers who reported having driven more than 14 hours on one or more days in the week prior to the interview or who had more than 72 driving and other work hours, including loading or unloading vehicles) were most likely to say they nodded off occasionally.

- Perception of fatigue as a problem: by nearly a 2 to 1 margin, drivers said fatigue was rarely or never a problem for them but it was often a problem for other drivers. Ten times as many drivers considered fatigue or tiredness always or often dangerous on the roads compared to those who considered it to be rarely a problem.

- Schedules and other work factors: more drivers operating on fixed schedules said fatigue was a problem for them personally than did drivers whose schedules were flexible. Drivers also were asked to name up to three factors they perceived as causing fatigue: the most common factors cited were driving long hours, loading and unloading freight, delays in loading, and lack of sleep. Drivers who reported having less than six hours of sleep before their trip were more likely to say poor rest in their [sleeper berth] was an important fatigue contributor. (p. 13)

- Countermeasures, personal: the three most common were pulling over when tired (81.7 percent), drinking caffeine-containing beverages (68.5 percent), and getting a good night's sleep before starting their trips (62.4 percent). Others: keeping fit (42.2 percent), sleep regular hours (32.1 percent), cigarettes, nicotine gum (43.7 percent), candies or chocolates (31.2 percent), pills or drugs (16.3 percent). These last three categories were more common among the drivers operating 14 hours or more daily and 72 hours or more per week.

- Countermeasures, operational: the top desired fatigue countermeasures cited were performing less loading and unloading (26.3 percent), having control over their schedule or planning own trip schedule (both items, 32.6 percent). However, 33.9 percent of drivers suggested no desired countermeasure.

- Night driving: 4.7 percent of drivers indicated "avoid night driving" as a countermeasure (Table 7, p. 16). Company drivers (348 of 726 interviewed) said their companies try to minimize night driving (Table 9, p.19). Another 4.6 percent of company drivers said their companies should do this.

- Daily work hours: the authors used three methods to analyze drivers' daily driving hours. They estimated that 17.5 percent of the drivers exceeded 14 hours of driving in an average working day and did this an average of twice per week. (p. 25). When they took non-driving work into account, the authors estimated that 55 percent of the drivers worked in excess of 14 hours in a day. (p. 26). Another 29 percent worked over 16 hours in the 24 hours prior to their interview, and 37 percent would have done more than 16 hours of work in the 24 hours prior. (pp. 26-27).

- Hours of sleep: about five percent reported having no sleep on one day during prior week; 12.5 percent less than four hours of sleep one or more work days in prior week; and about 30 percent obtained less than six hours of sleep on at least one work day. Prior to commencing their current trips, about two-thirds of the drivers had between 6 and 10 hours of sleep, but about 20 percent had less than 6 hours of sleep. (pp. 27-28).

- Weekly work hours (in week prior to interview): one-third drove 40-60 hours, 20 percent drove 60-80 hours; 17.5 percent drove more than 72 hours and about two percent drove over 100 hours. Accounting for non-driving work, about 30 percent worked over 72 hours and about 11 percent worked over 90 hours; and five percent of drivers worked over 100 hours.

The authors note that regulations on hours-of-service for truck drivers have never been enforced in Western Australia.

Reviewer's Notes: This study was derived entirely on self-reports. The interview form reproduced in an appendix to the report was 9 pages long and the authors did not state how long it took to administer. If an interview will take a long time to complete, generally fewer people will do it unless they have a very strong interest in participating. The sample size was fairly large, but there are unexplained and rather large differences (not discussed in this review) between drivers operating on north-south and east-west routes. The detailed analyses in the appendixes of the report indicate some important differences among drivers hauling perishable commodities such as frozen goods and livestock. Finally, there is a key difference between the United States and Australia long-distance transportation: there are very few rail lines in Australia, and trucks are the only transport mode available for long-distance freight movement between the major cities.

VanOuwerkerk, F. (1988). *Quality of Life and Social Costs; Working Conditions.* Study commissioned by Dutch Ministries of Transport and Social Affairs, Potterdam, The Netherlands.

This study was a follow-up to a finding from the 1981 roundtable of European Conference of Ministers of Transport that the European Economic Commission (EEC) Regulation 543/69. That regulation, setting forth requirements for driving and resting periods for international drivers, has apparently not had an influence on drivers' work.

The report describes the results of a survey involving 650 international truck drivers from 6 EEC countries. Interviews were conducted at major border crossings between the Netherlands, Germany and Belgium. Nearly two-thirds (62 percent) of the responding drivers were Dutch. Information was gathered via an interactive computer program, an activity analysis that was completed by the drivers and survey assistants, and the drivers' tachograph records or paper logbooks.

In general, the surveyed drivers stated they wanted to drive longer than the regulations permit (11 hours versus eight hours), but their overall work periods and rest periods basically coincided with their preferences. Close to one-third (31 percent) of drivers drove more than eight hours per day. Although the surveyed drivers drove an average of 42 hours per week, 25 percent drove more than 50 hours per week and five percent drove more than 67 hours per week.

EEC regulations in effect at the time of the survey set no limits on the working period or the working week. The surveyed drivers had an average 74-hour working week. However, for the French international drivers, 90 percent worked more than 60 hour week. Overall, 25 percent of the drivers worked more than 84 hours per week.

Drivers reported a median sleep time of 6.7 hours and a median rest period of 7 hours. They reported that the "minimum rest time [reduction from 11 hours to eight hours not more than two times per week] has become the rule" as far as both drivers and enforcement officials were concerned. Of the drivers the researchers estimated to have violated the hours-of-service regulations, 80 percent of them said they know how to tamper with their tachograph recordings.

The researchers also discussed the drivers' work-rest schedules. Following EEC regulations 'to the letter' can result in as short as a 17-hour cycle (8 hours of driving, 1 hour of breaks, 8 hours of rest time). Nearly 40 percent of drivers had work-rest cycles of 22 hours or less. For drivers who worked four or more days in a row, the researchers calculated an average work-rest cycle just under 18 hours.

Some 60 percent of drivers said they sleep or almost fell asleep at the wheel. Sixteen percent said they 'really' fell asleep, and 7 percent said they had caused a crash due to drowsiness/sleep at the wheel.

Abrams, C., Shultz, T., & Wylie, C.D. (1997) ***Commercial Motor Vehicle Driver Fatigue, Alertness, and Countermeasures Survey.*** **(Report No. FHWA-MC-99-0067) Washington, DC: Federal Highway Administration.**

This survey was performed to learn about commercial motor vehicle drivers whose schedule situation (irregularity, night driving, daytime sleeping) might contribute to fatigue and loss of alertness, as well as the methods drivers used to mitigate fatigue or its symptoms. The authors of this report used methods similar to previously published research (Braver et al. and Beilock et al.) to conduct a contemporary survey of long-distance CMV drivers with comparable demographic characteristics: drivers of tractor-trailers who drove at least

60,000 miles within the last year, and who had been on the road at least 24 hours at the time of the interview. The authors used a questionnaire designed to take no longer than 15 minutes to administer and interviewed 511 drivers at four geographically-diverse inspection stations.

The findings described in this summary relate to driver schedules, working conditions, and measures to mitigate fatigue.

Overall, nearly 85 percent of drivers drove irregular hours, drove an irregular route, and drove solo. Nearly one third (31.5 percent) of the drivers identified themselves as owner-operators. The average road trip lasted 13 days, the 50th percentile trip length was 7 days, and the 75th percentile was 18 days.

The authors found no statistically-significant differences in the stated rest needs among the categories of drivers (owner-operator, company driver, regular route, irregular route, solo, team): a driver reported needing an average of 7 hours of sleep on an average day. There was a slight difference between union and non-union drivers; the former reported needing about 31 minutes less sleep.

Just over 90 percent of the drivers reported that they usually used a sleeper berth while on the road. Almost three fourths of the drivers reported taking their sleep in a single period, spending eight to nine hours in the berth. Just over two thirds of the drivers who split their sleeper berth period reported usually spending four to five hours in the berth during one period. Almost 60 percent of drivers believed daytime sleeping was less restful than night sleeping. The main reasons they cited were "habit" or "night seems normal," "bothersome light and noise," and "their internal clock."

The researchers asked drivers how often they found themselves dozing or falling asleep at the wheel during the past month. Nearly three fourths of the drivers (72 percent) reported "none." Of the drivers who said they did experience these incidents, 53.1 percent reported them happening once or twice; 32.2 percent reported three to five times; but 3.5 percent responded that this was at least a daily occurrence. Almost 90 percent of these drivers said they were sometimes or always aware of the danger of falling asleep. The authors express a concern about their decision to continue to drive under such circumstances. The drivers reporting irregular schedules had statistically more reported incidents of dozing/sleeping than those drivers with regular schedules.

The authors requested information about breaks and how drivers used their break time. Most drivers stated they preferred to drive between four and five hours before a break. Solo drivers averaged about 51 minutes for breaks; teams averaged about nine minutes less. Among the activities reported, taking a nap came in fifth out of 7 items, with 3.1 percent of drivers reporting they always napped; 62.6 percent reporting they sometimes napped; and 33.9 percent reporting they never napped.

The drivers also answered a number of questions about work habits. Almost half the drivers said they sometimes get less sleep to cope with adverse driving conditions and delivery schedules. Just over one fifth of the drivers stated they usually physically load or unload freight. They reported an average driving time of 4.6 hours between breaks; the most common lengths of work break were 30 to 45 minutes and 60 to 75 minutes (roughly 30 percent of drivers in each category).

The researchers asked the drivers to suggest and rate activities for their effectiveness in keeping them alert while driving. The researchers placed the responses into four categories. Roughly 90 percent of the drivers rated one set of activities as very or somewhat effective (cooling the cab, stretching or adjusting seating position, and listening to radio or recorded music). The next set of activities (talking on citizens'-band radio, drinking caffeinated beverages) received around an 80 percent rating. The third set (chewing gum/candy, eating food, using tobacco/nicotine, and singing/talking to self) received ratings from 45 to 56 percent. The least-effective rated activity, at eight percent, was using an over-the-counter medication such as No-Doz. Just over one fourth of the drivers indicated they do not use these medications.

Because being awake long hours can contribute to fatigue, the researchers asked the drivers how long they had been awake before they began their current trip. The drivers reported an average time of 5.8 hours, but nearly 45 percent had been awake six or more hours; 38 percent, 6 to 12 hours; 3.7 percent, 13 to 16 hours; and 2.5 percent, over 17 hours. About two thirds of the drivers cited work related causes, with the remainder mixed between family/personal situations and weather/traffic conditions.

Hanowski, R.J., Wierwille, W.W., Gelaty, A.W., Early, N., & Dingus, T.A. (1998). ***Impact of Local/Short Haul Operations on Driver Fatigue, Task 1: Focus Group Summary and Analysis.*** **(Report No. FHWA-MC-98-029) Washington, DC: Federal Highway Administration.**

This report describes the initial phase of a study of driver fatigue in local and short-haul operations, defined as trips taking place primarily within 100 miles of the home base. Eighty-two drivers participated in 11 focus groups. Local/short haul drivers are a diverse group in terms of the variety of commodities they transport, the types of roads they travel on, and the amount and type of non-driving activities. The focus group drivers represented a variety of operations, included less-than-truckload common carrier, beverage/beer, snack foods, chemicals/fertilizers, gas/oil, building materials, concrete/dirt/gravel, and construction/heavy equipment.

From the Executive Summary: *Across the eleven sessions, drivers were able to generate fifteen general safety issues. The top five critical issues/causal factors, ranked in terms of importance, were (1) Problems caused by drivers of light vehicles (i.e., four-wheelers), (2) Stress due to time pressure, (3) Inattention, (4) Problems caused by roadway/dock design, and (5) Fatigue. Regarding fatigue, analyses confirmed that drivers who raised fatigue as a general safety issue had significantly less self-reported sleep per night (M=6.1 hours) as compared to drivers who did not raise fatigue as an issue (M = 6.7 hours).* (p. ii)

To further investigate the importance of fatigue, drivers were asked to generate and rank a list of fatigue-related issues. Across all sessions, twenty-two issues were raised. The top five issues, ranked in terms of importance, were: (1) Not enough sleep, (2) Hard/physical workday, (3) Heat/no air conditioning, (4) Waiting to unload, and (5) Irregular meal times. These findings support past research that has suggested that 'Not Enough Sleep' is the single best predictor for fatigue. (p. ii)

Neale, V.L., Robinson, G.S., Belz, S.M., Christian, E.V., & Dingus, T.A. (1998). ***Impact of Sleeper Berth Usage on Driver Fatigue: Analysis of Trucker Sleep Quality.*** **(Task 1 Report, Washington, DC): Federal Highway Administration.**

(Authors' Abstract) *This report presents the results of a literature review and ten focus groups which were conducted with long-haul drivers in eight cities across seven states. The* *purpose of these sessions was to gain an understanding, from the long-haul drivers' perspective, of the issues affecting the quality and quantity of sleep drivers receive as well as other issues that may affect drivers' levels of fatigue. A summary of the issues discussed is presented under the following categories: 1) sleep/rest and duty cycle issues, 2) equipment issues, 3) additional driver responsibilities, 4) facilities issues, 5) regulatory and enforcement issues, 6) driving and traffic issues, 7) terminus issues, 8) company dispatching issues, 9) training issues, and 10) miscellaneous issues. The results of drivers' rating of their sleep quality while at home and on the road are also presented. The information gathered from the focus groups is summarized into a list of drivers' recommendations for improving the fatigue level among long-haul drivers. Concerns that were highlighted by drivers in most or all of the focus groups included: 1) team driving, 2) equipment, 3) lack of rest area facilities, 4) private driver education, 5) loading and unloading cargo, and 6) pressure to drive. Based on the information gathered, independent and dependent variables are recommended for evaluation during an on-road study.*

Reviewers Note: This study is one of relatively few that focuses on the unique operational concerns of sleeper berth use and is also one of the only studies that will assess them outside the context of crash involvement. The FHWA anticipates commencing the on-road study in the fall of 1999.

Transport and General Workers Union 8/9-10 Branch and Sheffield Occupational Health Project (1998). ***What Makes Bus Driving Stressful? A Survey of Sheffield Bus Drivers.*** **London: Transport and General Workers' Union.**

This report presents the results of a survey of urban bus drivers in Sheffield, England. The drivers selected were assigned to three routes serving the city-center and urbanized area. All were members of the union sponsoring the study. Of 148 survey forms distributed, 111 (75 percent) were returned. The survey covered driver demographics, shift patterns and hours of sleep, working conditions (including driving time) and communications with their management. The drivers pointed to seven areas of concern: long hours behind the wheel (up to 5 ½ hours at a stretch, and split shifts that last up to 12 ½ hours); schedules that are difficult or impossible to maintain (41 percent of the drivers reported feeling pressured and

24 percent reported feeling irritable when they were running behind schedule); lack of sleep (some 52 percent of early shift drivers reported an average of five hours or less sleep per night); irregular meal times; lack of consideration and cooperation from other road users; aggressive passengers; and communications with management.

Reviewer's Note: Although this report deals with urban transit drivers, many of the issues are common to regional motorcoach and tour bus operations as well as to local pickup and delivery operations.

Operational issues: motor carrier perspective

The following two survey-based studies focus on motor carriers' perspectives on operational issues (driver fatigue/loss-of-alertness, hours-of-service regulations, potential alternatives to prescriptive approaches to driver alertness management, driver compensation, and other topics) in Australia and in the United States.

Arnold, P., Hartley, E.R., Penna, F., Hochstadt, D., Corry, A., and Feyer, A-M. (1996). ***Fatigue in the Western Australian Transport Industry, Part Three: The Company Perspective.*** **Western Australia: Murdoch University.**

This is the third report in a 3-part series (see Arnold et al. above). The authors contacted 88 motor carriers with head offices in 3 cities in Western Australia; 84 agreed to participate. The companies varied in size from single-person operations to companies with over 100 drivers. Over half the companies employed between 1 and 10 drivers. Just over half contracted with owner-operators. The smallest companies generally hired "freelance" [independent] drivers. The 4 predominant types of freight were general freight (57.1 percent), bulk materials (46.4 percent), produce (22.6 percent), and freezer/chiller goods (19.0 percent). The authors interviewed managers, personnel officers, or chief executive officers. As in the other surveys, chi-square analyses were used to assess statistical significance and only results exceeding 99 percent confidence level were reported.

Drivers' pay. Driver payment policies varied by company and by the type of driver (employee, subcontractor, freelance). Company drivers were more likely to be paid a regular wage (hourly or regular plus overtime). Subcontractors were more likely to be paid by the kilometer or by another method. Just over half (53.6 percent) said drivers were paid in accord with the 1983 Federal Award [wage guidelines] but about 40 percent said they were not. Nearly 40 percent of companies compensated their drivers for loading and unloading freight; another 33 percent paid drivers by the hour for this work, but 10 percent stated that they did not pay drivers for this work. As a rule, neither drivers nor motor carriers (roughly 85 percent) are compensated extra for urgent deliveries.

Computation of trip times. Trip times are most often established by their distances (59.5 percent of companies use this method). Consultations between managers and drivers and trial trips are used about one fourth of the time each. About one third of the companies added extra time to drivers' schedules to accommodate rest, sleep, breakdowns, and other factors; another one third said they added time for rest, but just over one fourth said that they did not add time to schedules. (p. 9) Just over one third of the companies indicated they would reduce trip times to accommodate clients by using two-up [two-driver] crews, hiring freelance drivers, or reorganizing schedules or other clients' loads. One company stated it would ask drivers to forgo sleep. (p. 10) If no rested drivers were available for urgent loads, 28.6 percent of the companies said they would hire a freelance driver, six percent would send a driver out without adequate rest, and nearly half stated their companies had other strategies but did not describe them.

Role of driver feedback. More than 75 percent of companies investigated late deliveries. Just under one third would interview the driver; one fifth would revise the schedule; just under one third would do nothing; and roughly 40 percent noted "other." (Table 10, p. 12)

Fatigue management practices, limits on driving hours. Over three fourths of the motor carriers stated they have no "formal" fatigue management policy or plan. However, they stated they do attempt to control driver fatigue through various practices, including restrictions they place on driving hours (used in 59.5 percent of companies), driver self-regulation (48.8 percent), and "restoring drivers to a truck" [assigning drivers to a particular vehicle]. Fifty percent indicated other strategies but did not specify them. (Table 13) On the other hand, about half the companies said they did not place any restriction on daily driving hours. (p. 15) Of those companies that did limit driving hours, over 44 percent had limits of 15 to 16 or 17 to 18 hours, and another 27.7 percent had limits of 13 to 14 hours. (Table 14, p. 5) About 40 percent of the companies did not limit weekly driving hours; of those that did, some 18.7 percent had limits of 71-80, 81-90, or over 90 hours. (Table 15, p. 16). Over three fourths of companies indicated they did not provide drivers with education in managing fatigue.

Monitoring drivers. Just over half the companies reported they monitored drivers' experience with fatigue. Most (70 percent) said they relied upon customers' feedback; about two thirds used reports from other drivers, and nearly the same numbers interviewed drivers or analyzed accidents. Nearly two thirds of the motor carriers stated that they regularly assessed drivers' fitness to drive, and nearly three fourths of them said they used simple visual assessment. (p. 22) Nearly two thirds of the companies would send an apparently-fatigued driver home. (See Tables 24 to 26, p. 23). With regard to drivers' use of alcohol or drugs, 51.3 percent of the motor carriers would immediately dismiss a driver who was intoxicated or possessing or using drugs; another 46.8 percent indicated these actions were not acceptable but did not specify what actions they would take. Over 80 percent reported none of their drivers took drugs, but they believed that more drivers from other companies did. About two thirds would generally not estimate a percentage, but the rest expressed a belief that more than 40 percent of drivers used drugs; 6.8 percent of companies indicated a level of acceptance of drug use. (See p. 26 for full discussion).

Driver feedback. Over 90 percent of companies said they obtained drivers' feedback but the authors stated they did not learn if this was a formal or informal process or whether the results were solicited or not. Nearly two thirds of companies said that problems with driving hours or delivery schedules were rarely brought up.

Company perceptions about driver fatigue. Eighty eight percent of companies indicated that they believed fatigue was never or rarely a problem for their drivers. However 41.7 percent believe it was a frequent problem for the industry in general, and another 45.2 percent believed it was sometimes a problem for the industry. The 3 top factors selected from a list provided by the researchers were driving long hours, lack of sleep, and overly-tight schedules. Loading delays were cited by 7.1 percent of companies – the authors contrast this to the drivers' perception of this as a major contributor. (Table 33, p. 32 provides a list of contributors to fatigue. "Driving between 2:00 and 5:00 am" was tied for fifth place with driver inexperience, with 19 percent of companies citing it.) In general, companies said many fatigue management strategies were not applicable to them, that drivers did not want or would not accept them, or cited financial or industry-oriented reasons for not using them.

Griffin, G., Rodriguez, J., Lantz, B. (1992). ***Evaluation of the Impact of Changes in the Hours of Service Regulations on Efficiency, Drivers, and Safety.*** **(Report No. 93) Fargo, North Dakota: The Upper Great Plains Transportation Institute, North Dakota State University.**

The authors modeled different schedule scenarios based upon a 1992 FHWA proposal to permit motor carriers and drivers to "reset" their 60 or 70-hour duty limit after a period of at least 24 consecutive hours off-duty and compared them to the current 70-hour limit.

The authors estimated "weekly" (7-day) totals based on the FHWA proposal, of up to 88 hours of driving (if no on-duty-non-driving is assumed) or up to 100 hours of on-duty time. They also computed 16-day on-duty periods as high as 200 hours of driving if no other on-duty tasks are performed or 216 hours based upon 15-hour continuous on-duty times. The authors did not provide assessments on the ability of human performance to be sustained for these periods of time, nor for multiple 7-day periods with no extended off-duty time.

The authors noted, *The implications for safety are the most difficult to determine . . . a search for secondary accident data that would be useful in addressing the implications that the 24-hour rule would have on safety was made at the state and federal level. No data was identified that would be statistically valid . . .* (p. 37) Their conversations with California Trucking Association staff *indicated that they were not aware that the state laws governing intrastate hours of service caused increased safety problems.* (p. 40) They also cited conversations with officials from the Florida Office of Motor Carrier Compliance and a senior manager from the Florida Trucking Association *felt the Florida laws [allowing longer intrastate HOS] improved safety.* (p. 41)

Reviewer's Notes: This study was funded by the Interstate Truckload Carriers Conference of the American Trucking Associations. This organization advocated the "24-hour-reset" proposal that would have had the effect of substantially increasing allowable cumulative multiday on-duty and driving time. Neither the FHWA nor proponents of the change were able to provide data to support the notion that safety would not be compromised. The FHWA withdrew the proposal in February 1993.

Florida and California have some of the highest numbers of fatal CMV crashes of the States. The FHWA had withheld Florida's Motor Carrier Safety Assistance Program (MCSAP) funding for nonconformity with HOS tolerance guidelines at the time this study was performed. A California Highway Patrol study of crash experience related to a limited waiver from hours-of-service regulations provided to motor carriers engaged in certain agricultural operations cited later in this review also provides a contradictory view of the driver-fatigue-related highway safety picture.

Hours-of-service violations and issues related to working conditions

The following reports, also based upon information collected from drivers, describe working conditions and violations of hours-of-service regulations that are considered by some to be endemic.

Braver, E.R., Preusser, C.W., Preusser, D.F., Baum, H.M., Beilock, R., & Ulmer, R. (1992). ***Who Violates Work-hour Rules? A Survey of Tractor-Trailer Drivers.*** **Washington, DC: Insurance Institute for Highway Safety.**

The researchers interviewed 1,249 drivers at truck inspection stations, truck stops, and agricultural inspection stations in Connecticut, Florida, Oklahoma, and Oregon. They conducted over three quarters (78 percent) of the interviews at Florida agricultural inspection stations or at safety inspection stations in the other three States. The researchers described the interview to the drivers as an opinion survey of truck drivers concerning the DOT hours-of-service (HOS) regulations. Only drivers of tractor-trailers who also reported spending one or more nights away from home when on a trip were eligible to participate. Over 90 percent of eligible drivers elected to participate.

The researchers classified the interviewed drivers as HOS violators or non-violators. Criteria for violators were either: (1) working or driving more than 70 hours per week if the driver was on an eight-day work schedule [the motor carrier operates CMVs every day of the week]; or (2) working or driving more than 60 hours per week if the driver was on a seven-day schedule [the motor carrier operates CMVs up to 6 days per week]; or the driver reported working longer than permitted during the month preceding the interview.

Overall, the authors classified 73 percent of interviewed drivers as violators. The proportions varied from 69 percent (FL) to 82 percent (OR). Overall, 19 percent of the surveyed drivers stated they dozed or fell asleep at the wheel one or more times during the prior month (low of 10 percent in the OK interviews; high of 23 percent in the FL interviews). They reported statistically significant levels of association between "violator" status and the following self-reported variables: lower per-mile pay, higher annual mileage, road trips lasting more than one week, employment by a for-hire rather than a private motor carrier and driving an irregular route.

Beilock, R. (1988). ***RCCC Motor Carrier Safety Survey.*** **Alexandria, VA: Regular Common Carrier Conference.**

This was the third report in a series of annual surveys conducted under the sponsorship of the Regular Common Carrier Conference, a national trade association representing general freight trucking companies that specialize in hauling less-than-truckload shipments throughout the United States. The surveys focused on different safety issues from year to year. One of the focuses of the 1988 survey was the role of driver fatigue in safety.

There were 878 drivers participating in this survey. On average, they believed they normally could drive 10.6 hours before they required a long rest. Beilock noted: *however, a half a century of Federal regulations infusing drivers with the 10-hour figure may affect the conveniently corroboratory result.* (Footnote 30, p. 35). However, 30 percent believed they could drive longer than 16 hours, and 3 percent believed they could safely drive 20 hours. Beilock added: *The reader should bear in mind that these are the drivers' estimates of how long they can drive before becoming seriously tired . . . Driver estimates of the importance of fatigue in truck accidents provide an indication of how much truck drivers think they put themselves and the public at risk by driving when tired. Their responses reveal widespread awareness of and concern for driver fatigue problems.* (p. 35) The surveyed drivers estimated, on the average, 36 percent of truck accidents are due to driver fatigue.

Beilock asked an open ended question: what should be done to decrease the driver fatigue problem? The top responses, and the percentages, were as follows:

- Eliminate violation-inducing schedules by imposing penalties upon, or monitoring dispatchers, shippers, and receivers (33 percent).
- Increase enforcement efforts on the highways (16 percent).
- Increase driver earnings to allow them to drive fewer miles while still earning a decent living (11 percent).

- Eliminate hours-of-service regulations and allow drivers to use their own discretion (10 percent).
- Do not require drivers to load or unload (8 percent).

Beilock, R. (1995). Schedule Induced Hours-of-service and Speed Limit Violations among Tractor-trailer Drivers. ***Accident Analysis and Prevention*** **27(1) 33-42.**

This was a survey study of 500 long-distance truck drivers exiting Florida agricultural inspection stations. Interviews were attempted with every driver of a loaded combination vehicle and every third driver of an empty combination vehicle. Beilock stated that the questions were presented directly to the participants in an attempt to avoid response bias and to make it unlikely that they would realize their responses would be used to compute their compliance with the HOS regulations.

The drivers were asked where the current trip originated, the location and time of the next pickup or delivery, if there was a co-driver, and the number of miles driven over the previous 7 days. The analysis of their responses assumed, among other things, that the drivers had not taken extended rests prior to reaching the interview site and that they drove the same distance each day. It also used the conditions of the FHWA's Notice of Policy Statement (43 FR 7622, February 24, 1978): this policy statement deals with average travel distances for a schedule to be considered suspect or likely to be in violation with respect to posted speed limits and the hours of service regulations.

Beilock found between 17 and 30 percent of the drivers had violation-suspect schedules and between 14 and 26 percent had potentially violation-inducing schedules. Solo drivers were statistically far more likely to have violation-suspect or -inducing schedules than team drivers. The same trend held for drivers hauling refrigerated loads compared to unrefrigerated loads, and regular-route drivers compared to irregular-route drivers. Beilock attributed the latter to the impact of a delayed delivery on a larger part of the motor carrier's overall system. Drivers whose current trips were longer were also more likely to have violation-suspect or -inducing schedules.

The papers and studies cited in this section are concerned with the setting of workshifts, the directions of shift rotations, and determination of appropriate amounts of time off between shifts to permit workers to obtain restorative sleep.

Hildebrandt, G. (1976). Outline of Chronohygiene. *Chronobiologia, III* (2). pp. 113-126. University of Marburg/Lahn, West Germany: Institut für Arbeitsphysiologie und Rehabilitationsforschung.

This paper presents an overview of influences of rhythmic cycles on biological functions. The author illustrates rhythmic functions with periods ranging from thousandths of seconds (such as nerve activity) to complex regulations ranging from 1 day to 1 year, and places a special focus upon respiratory and circulatory patterns with periods ranging form 0.2 to 120 seconds.

Hildebrandt shows a series of smooth curves coordinated in both frequency and phase among these rhythms as illustrating a healthy state. He notes that this ideal state is subject to disturbances arising from activity and functional loads placed upon the organism. *An organism modifies its abilities periodically in accordance with its integration into the rhythmic environment, causing the formation of certain risk cycles, for instance . . .* (pp. 117-118). He cites as examples seasonal variation in risk for cardiovascular disease, as well as circadian variations in biological functioning, reaction time to acoustic signals, and vigilance. In addition to circadian rhythm effects, he cites work by other researchers indicating that night work appears to affect other faster rhythms, such as pulse rate. He speculates whether the degree of disturbance might be usable as a criterion for a person's suitability for night work.

Rutenfranz, J., Knauth, P., & Colquhoun, W. (1976). Hours of Work and Shiftwork. *Ergonomics 19* (3), 331-340.

This paper presents an overview of health and social concerns arising from long working hours and shiftwork. The authors consider elements of a workday (work, leisure, sleep); they note work by others indicating that sleep during the day has less recuperative value than sleep during the night, and also that an insufficient amount of "genuine leisure time " [i.e., time over and above that needed for personal needs] can result in decreased sleeping time. Although the authors hold that a daily working time of 8 hours is optimal, they note that environmental influences and levels of mental or emotional stress can demand limitations or allow lengthening of the workday.

Turning to shiftwork, the authors illustrate social, technological, and economic rationales for it, but they also note *Ergonomic or work-medical reasons for the introduction of shiftwork do not exist.* (p. 333) They cite research documenting digestive and sleep disorders among shiftworkers. Shiftworkers' sleep is shorter and of poorer quality and quantity as measured by EEG criteria. They also have considerable difficulties reentraining [reestablishing timing of] physiological functions after shiftwork. Finally, shiftwork has adverse impacts on family and social life.

The authors offer several criteria for developing optimal shiftwork schedules: (1) single night shifts are preferred over consecutive s; (2) at least 24 hours free time should be allowed after each night shift; (3) the length of a shift cycle should not be too long; (4) the length of the shift should be related to the type of work; and (5) in connection with continuous shiftwork, as many free weekends as possible should be arranged.

Knauth, P., Rohmert, W., & Rutenfranz, J. (1979). Systematic Selection of Shift Plans for Continuous Production with the Aid of Work-physiological Criteria. ***Applied Ergonomics 10*** **(1), 9-15.**

(Authors' Abstract): *Taking into account the numerous theoretically possible shift systems, we chose sensible shift systems with the aid of objective work-physiological criteria, for example, the duration of the daily working time, the positioning and duration of the sleep, and recreation time.*

With an agreed [upon] *40 hour week shift, systems with a weekly working time of 42 hour are more advantageous. If the shifts are equally attended over 24 hours, the following shift systems are recommended: when you have 8 hour shifts the relation between the number of working days and the number of free days should be "3 n/n", whereby n must be larger than 1, within one shift rota* [rotation]. *In the exceptional case of a 12 hour shift* *the corresponding relation should by "2 n/n". Further unsuitable and recommended shift plan examples are demonstrated for these shift systems.* (p. 9)

Reviewer's Notes: Most shift schedules that are presented for consideration in workplace settings are based upon a 40-hour workweek, and, for the most part, a work day of 8 hours or less. The authors have presented here a novel 42-hour workweek as mathematically better suited to setting schedules because a 7-day, 168-hour week can be evenly divided into 42-hour shifts, utilizing 4 crews.

Miller, J.C. (1992). *Fundamentals of Shift Work Scheduling*. (Available from author.)

This is a general guide to designing shiftwork schedules. The chapters cover the following topics: shift systems (relative numbers of work and free days); shift lengths (12 hours versus 8 hours); numbers of crews required to cover the work; shift sequences of work and free days, with shifts rotating forward on the clock; shift plan alignments with the calendar week; shift change times; shift pay differentials; employment ratios to allow for staffing to allow for leave and coverage during holidays); and a general discussion of methods to assess shift work schedules (direct assessment, indirect assessment, worker self-reports, fitness-for-duty tests). Miller adapts the shiftwork-planning goals established by Knauth et al. and Hildebrandt (see synopses above).

Grandjean, E. (1982). Working Hours and Eating Habits. In *Fitting the Task to the Man – an Ergonomic Approach*. London: Taylor & Francis.

The portion of the chapter synopsized here discusses working time, worker performance in terms of work-unit outputs and the effects of excessive overtime on worker absenteeism.

Grandjean cites studies performed in industrial settings to draw relationships between workers' output in self-paced tasks and the amount of time worked in a shift. Shortened workdays resulted in higher hourly outputs, and workers completed their work earlier and took fewer voluntary rest pauses. Longer workdays, over 10 hours daily, resulted in lower total output – the slowed pace of work outstripped the longer work period. He cites other studies that illustrated trends in increased worker sickness and absenteeism during periods of increased overtime; one study by Behrens illustrated a rise in monthly average sickness rates from approximately 3.3 percent to 5.3 percent during a summertime period when monthly hours of overtime rose from 42,000 to 83,000.

Reviewer's Notes: Many other studies of shiftworkers and other workers engaged in long work periods have also noted increased absenteeism, reduced unit outputs (see Belenky et al. (1994) for examples involving soldiers), increased subjective stress, and negative impacts on job satisfaction and family life.

The following material, from the same chapter, discusses the influence of shiftwork on workers' sleep quality and quantity.

Grandjean cites several studies illustrating frequent cases of disturbed sleep among nighttime workers. In two studies comparing night shift and dayshift workers, the ratios of workers reporting disturbed sleep were 66 percent to 11 percent and 63 percent to 5 percent. In two other studies of workers who voluntarily worked the night shift, 84 to 97 percent reported disturbed sleep. He also cited EEG studies of sleep in night shift workers by Lille.

From Grandjean's description: *It appeared that daytime sleep was distinctly shorter than night sleep the workers took on their rest day. The average length of sleep in the daytime was six hours, whereas on the rest day the average varied between six and twelve hours, with longer sleep on the second of the two rest days than on the first* (pp. 248-249). Grandjean cites Lille's term "sleep debt" to describe the longer sleep periods the nightshift workers took on their two between-shift rest days and noted that a single night's sleep was apparently insufficient to "pay it back."

Vidaček, S., Kaliterna, L, & Radošević-Vidaček, B. (1986). Productivity on a Weekly Rotating Shift System: Circadian Adjustment and Sleep Deprivation Effects? *Ergonomics 29* (12) 1583-1590.

This study was performed to assess the relative roles of circadian rhythm effects and cumulative sleep deprivation over several consecutive night shifts in shift workers. The researchers studied 53 women shiftworkers in an electronics component factory. The shiftworkers worked backwards-rotating shifts, with five consecutive workdays followed by two days off. Their work productivity was monitored over a four-month period. Thirty of the women completed a questionnaire concerning their sleep habits while on the various shifts

The workers on the afternoon shift reported sleeping the longest between successive afternoon shifts. Single and married workers on night shifts and morning shifts slept for shorter periods, but the sleeps between successive morning shifts were the shortest for the single workers and the sleeps between successive night shifts shortest for the married workers. Productivity showed a strong statistical relationship to the shift worked – it was highest in the afternoon shifts and lowest in the night shifts.

The authors conclude that: (1) both circadian rhythms and sleep deprivation affected the productivity of the shiftworkers in this study; (2) social factors, such as family commitments, can influence productivity. They stated it was not clear whether the shiftworkers were still adjusting to the circadian rhythm of the night shift after their third day or whether they were seeing the effects of cumulative sleep deprivation. They also provided a caveat to their results, noting that the workers in this study performed tasks that were simple perceptual-motor-productivity in nature.

Williamson, A.M. & Sanderson, J.W. (1986). Changing the Speed of Shift Rotation: A Field Study. *Ergonomics 29* (9), 1085-1096.

There are two views concerning the rapidity of shift rotation. Some researchers believe rapidly-rotating shifts (less than seven days on a shift) are preferable because they cause less disruption of circadian rhythms. However, other researchers have noted increased worker satisfaction when the shifts rotate slowly (21 days between rotations) and that the direction of the shift rotation is more important than the amount of time between rotations.

The authors of this study had the opportunity to compare shiftworkers' feedback as they changed from a seven-day clockwise shift rotation to a three-day clockwise shift rotation. The workers staffed an emergency dispatching facility. Their original schedule called for seven straight [consecutive] shifts, followed by one to four (average of two) days off. The new schedule also limited night shifts to three or fewer. Usually two night shifts were followed by three days off. The researchers studied workers employed before (33 total); after (26 total); and both before and after the change (16). The workers kept diaries to record sleep and food intake, completed questionnaires on the social environment of their work settings and their anxiety levels, and were interviewed by the researchers. The self-assessments were completed before and five months after the shift schedule change.

The authors stated in their discussion: *The results of this study show clearly that changing a shift roster from a traditional, slowly rotating cycle to a more rapidly rotating one can improve the subjective health and well-being of those who work it. Job satisfaction improved markedly and the controllers' scores on the Work Environment Scale reflected improvement of the work pressure dimension.* (p. 1092). The authors also noted significant decreases in the workers' reports of digestive disturbances, headaches, high blood pressure, anxiety, and sleep disturbances between the first and second assessments. They attribute this, in part, to the new schedule's *reduction in the consecutive number of the more anti-social shifts.* (p. 1094.)

Reviewer's Notes: Most researchers consider a clockwise rotation preferable because it conforms with the forward phase-shift of the natural day, some 24 1/4 hours. Much important information can be gained from the body of scientific shiftwork literature. Most studies of shiftworkers focus on situations where the workplace is fixed, such as an industrial plant or hospital, so they do not consider the unique demands of nonscheduled long-distance transportation. However, many findings can be applied directly or with adjustments to local transportation and scheduled regional and long-distance transportation. Others, such as regularity of shift scheduling and sleep periods, can be tailored for use by nonscheduled transportation operators.

Rosa, R.R., Colligan, W.J., & Lewis, P. (1989). Extended Workdays: Effects of 8-hour and 12-hour Rotating Shift Schedules on Performance, Subjective Alertness, Sleep Patterns, and Psychosocial Variables. *Work & Stress 3* (1) 21-32.

Rosa, R.R. (1991). Performance, Alertness, and Sleep after 3.5 Years of 12 h Shifts: a Follow-Up Study. *Work & Stress 5* (2) 107-116.

Rosa, R.R. & Bonnet, M.H. (1993). Performance and Alertness on 8 h and 12 h Rotating Shifts at a Natural Gas Utility. *Ergonomics 36* (10) 1177-1193.

These three studies follow workers at a continuous process plant and a natural gas utility whose workplaces changed their operations from three 8-hour rotating shifts to two 12-hour rotating shifts. The change in shifts also affected the number of consecutive days worked and the number of days off: on the 8-hour schedule, the workers worked five to seven consecutive days with two days off between shift changes; on the 12-hour schedule, the workers worked three to four consecutive days with three to seven days off between shift changes. All data was collected within the workplace setting. The 8-hour shifts rotated forward (clockwise). The process plant operators' work tasks involved monitoring control panels and computers, which the authors associated with requiring cognitive/problem-solving and maintenance of attention. Most of the gas utility workers tasks involved maintenance, assessed by the authors as demanding high levels of physical activity.

The subjects were volunteers. Most of them were men between the ages of 26 and 41. They were asked to perform a computer-based set of performance tests (National Institute of Occupational Safety and Health Fatigue Test Battery), provide subjective assessments of alertness and mood, and keep sleep diaries. The continuous-process plant workers participated in the study setting immediately prior to the change from 8 hour to 12 hour shifts, directly following the implementation of the 12 hour shifts, and again 7 months after and approximately 3.5 years after the 12 hour shifts were implemented. Not all subjects completed all the assessments, but 20 of the process plant workers completed questionnaires and 15 completed the computerized test battery in all phases of the study. In the gas utility, 5 workers were tested before and after the shift change, but others were tested only on the 8 hour or the 12 hour shifts.

From the authors' abstracts: *After seven months adaptation to the new schedule, there were decrements in the laboratory-type tests of performance/alertness which could be attributed to the extra 4 hours of work per day. There were also reductions in sleep, and disruptions of other physical activities during the 12-hour workdays. However, increases in self-reported stress were attenuated by the shortened workweek . . .* (Rosa, Colligan, & Lewis, p. 21) *Long-term follow-up testing revealed persistent decrements in performance and alertness attributable to 12 hour shifts, and 1-3 hour reductions in total sleep time after 12 hour night shifts. Little deterioration in performance or alertness was observed across the workweek, which suggested day-to-day recovery from the extended workshift. The popularity of the 12 h shift schedule at this worksite indicates that the workers are willing to* *tolerate extra fatigue to derive other benefits from this schedule."* . . (Rosa, p. 107) . *The results* [of the study of gas utility workers, whose work required high levels of physical activity] *are consistent with our first workaday study of 12 hour shifts and indicate extra caution should be exercised when scheduling critical activities for extended workshifts, especially extended night shifts.* (Rosa & Bonnett, p. 1177)

Reviewer's Notes: All of these studies found changes in subjects' performance according to both time of day and time on task. The authors' regression analysis in the 1989 study found statistically-significant effects for schedule type, time-on-shift, circadian rhythm, and the interaction of time-on-shift with circadian rhythm. Analysis of variance performed in the 1991 and 1993 studies found variations in performance and subjective state associated with both time on task and circadian rhythms. In the 1991 study, there was a striking similarity in performance test scores (grammatical reasoning and dual reaction time) and subjective sleepiness between the 8-hour and 12-hour shift workers during the first- and second-shift periods (roughly 7:00 a.m. to 11:00 p.m.).

In a telephone conversation (9/21/98) with Dr. Rosa, the lead author of these studies, Dr. Rosa indicated that it is important to consider a broad spectrum of workplace conditions in assessing the potential effects of shift changes. These conditions include but are not limited to overall shift length, the time of day when work is performed, circadian rhythms, length and timing of breaks, workplace coverage when workers are absent, and workplace stressors. Dr. Rosa also indicated that contemporary European shiftwork practices appear to be moving toward limiting the number of consecutive 12-hour workshift assignments and providing periods of 24-48 hours off between a set of shifts and longer periods off after a series of night shifts.

Wylie, C.D., Shultz, T., Miller, J.C., & Mitler, M.M. (1997). *Commercial Motor Vehicle Driver Rest Periods and Recovery of Performance.* (Report No. TP 12850E) Montreal: Transport Canada. 65

This study was a follow-on to Wylie et al. (1996). The following is taken from the Abstract of this report:

The purpose of the study was to assess the "recovery" effects of zero, one, and two workdays off on driver fatigue, alertness, and performance. It involved 25 of the 40 drivers who participated in the two 13-hour observational conditions of the DFAS. Drivers had nominally 12, 36, and 48 hours time off after the fourth workday.

For one workday off (36 hours), there was: (1) no objective evidence of driver recovery; (2) some improvement in drivers subjective feeling reflected by self-rating, although this could be a reflection of driver expectation of recovery; (3) for day-start drivers, some increase in the amount of sleep obtained during time off; and (4) for night-start drivers, interference with work-rest patterns and less sleep during time off.

For two workdays off (i.e., 48 hours), there was no objective evidence of driver recovery although the statistical power of the tests to detect recovery effects was not high because of random variation associated with the smaller number of drivers. (p. iii)

Smiley, A. & Heslegrave, R. (1997). *A 36-Hour Recovery Period for Truck Drivers: Synopsis of Current Scientific Knowledge.* (Report No. TP 13035E) Montreal: Transport Canada.

This report was based upon a broad review of scientific literature on rest and recovery requirements from acute and cumulative fatigue due to extended hours of work during the day and across several days.

The authors found only one study (Wylie et al., 1997) that specifically dealt with an operational schedule that would be permitted under a 36-hour reset scenario. The authors state this is mainly because such a short reset period would result in schedules that would exceed current hours-of-work regulations in most countries. They note that Wylie and his co-authors, as well as the reviewers, considered data from this study to be more suggestive of trends because of the small number of subjects and the fact that sleep during recovery periods was not recorded using full polysomnography (as were the sleep periods during the work periods).

Smiley and Heslegrave cite several other scientific studies dealing with recovery time. A 1967 study by Lille suggested that a single day off was insufficient for night workers to recover after a sleep debt accumulated over five days. Other studies indicated a preference for a three-day rest period compared to a two-day period after three 12-hour night shifts; a preference for two days and three days off over one day off when comparing automatic brakings experienced by locomotive engineers; and a 1994 literature review indicating two nights of recovery sleep as usually being sufficient to allow near full recovery after extended periods of sleep loss. Quoting from their summary: *[Wylie et al. (1997)] concluded there was no objective evidence of driver recovery from the 36 hours of time off. In terms of sleep duration, the 36-hour off-duty period appeared to impact the day and night drivers differently. For drivers starting their shift by day, some increase was observed in the amount of sleep obtained during the 36 hours of time off. On the other hand, the one workday off appears to have resulted in less sleep for drivers starting their shifts at night. In all likelihood, these drivers resumed day shift sleep-wake patterns on their time off, even though the time off was insufficient for accommodation."* (p. viii)

Wylie and colleagues' sleep data and driving performance (lane-tracking) data from their study from the daytime drivers suggested some recovery after 36 hours and apparent full recovery after 48 hours off-duty. The 48-hours off was equivalent to two work cycles off.

The night drivers were examined after only a 36-hour off-duty period. Overall, they performed less well than the day drivers. To begin with, their lane-tracking performance was always worse than the day drivers, and it declined from one work period to the next. However, the decline in lane-tracking ability was somewhat less after the 36-hours off.

Smiley and Heslegrave conclude: *Nevertheless, although the available research is sparse, it is sufficient to raise concerns about a 36 hour reset that would allow drivers to accumulate up to 92 hours on-duty within a seven-day period, particularly for night driving. It is also clear that there is insufficient scientific foundation on which to base prescriptive solutions for appropriate rest periods.* (p. 14)

Vespa, S., Rhodes, R., Heslegrave, R., Smiley, A., & Baranski, J. (1998). *Options for Changes to Hours of Service for Commercial Vehicle Drivers.* (Report No. TP 13309E) Montreal, Quebec: Transportation Development Centre, Safety and Security Group, Transport Canada.

(Authors' Abstract):*This report presents options dealing with potential changes to the Canadian hours of service (HOS) regulations. They were developed by an expert panel,* *established by Transport Canada (TC), that included experts in shiftwork, sleep and human performance. The proposals provide ideas for remedying certain deficiencies in the way that current regulations address (or fail to address) those driver fatigue factors that are accepted as being among the most significant. A number of national and international considerations as well as implementation issues associated with instituting HOS changes are discussed.*

The report also lists many current commercial driver practices that are considered poor from the fatigue perspective, and describes the psychophysiological concerns and consequences on driving safety associated with each. A taxonomy of good practice for work and rest scheduling of commercial drivers is presented, based on what is known about human physiology and fatigue while being mindful of motor carrier and driver operational considerations.

Transport Canada has taken the position that HOS changes should be guided by currently available scientific knowledge. The options presented are not intended to reflect TC policy or management decisions, nor to provide a recommended course of action. Rather, they are intended to stimulate discussions with stakeholders, by illustrating potential approaches to incorporating scientific knowledge on sleep, circadian rhythms and human performance into an HOS regulatory framework.

The authors of the report include a series of "core options" to address basic changes to reflect current understanding of alertness and performance influences of schedules (time of day, time on task, sleep needs); "recommended options" they describe as suggesting additional improvements, and "special circumstances" to address specific operational environments and situations, such as team drivers and drivers who run out of hours close to their destination. They address both daily (24-hour period) cycles and multiday cycles.

For daily work/rest cycles: establish a 24-hour period as the basic cycle; decrease the maximum on-duty time in that period from 16 to 14 hours; increase the minimum total off-duty time from 8 to 10 hours; require a minimum continuous off-duty period of 8 hours; require a two hour off-duty period between midnight and 6:00 a.m.; eliminate the split-rest provision in the HOS regulations; do not distinguish between driving and non-driving work periods. Recommended options include increasing the minimum continuous off-duty period from 8 to 9 hours; decreasing from 14 to 13 hours the maximum total on-duty time within any

24 consecutive hours that include more than one hour on-duty between midnight and 6:00 a.m.; require 30 minutes of rest from driving for every five hours on duty. Special circumstances for team drivers using sleeper berths would allow them to each take two periods of four continuous hours instead of the eight required for other drivers, and require a minimum continuous off-duty period of four hours after no more than eight consecutive hours on duty. A special provision for drivers exhausting their available hours would allow drivers to take two additional hours on-duty provided they first had a two-hour off-duty period.

For multiday work-rest cycles, the recommended options include: promote work/rest cycle regularity; maintain the existing on-duty maximums (60 hours in seven days, 70 hours in eight days, 120 hours in 14 days); treat off-duty recovery periods in terms of night sleeps (hours between midnight and 6:00 a.m.); require a two-night (plus intervening day) off-duty period within any consecutive seven-day period having more than 42 hours on-duty; and require a two-night (plus intervening day) off-duty period after four consecutive nights on duty. A recommended option would modify the 120-hour/14 day cycle to include the two-night off-duty period and to eliminate the 60/7 and 70/8 cycles. A special provision for drivers exhausting their available hours would allow drivers to take eight additional hours on-duty provided they first had a eight-hour off-duty period.

The expert panel also noted a need to consider National-provincial issues, as well as reciprocity concerns between Canada and the United States.

Hours-of-Service Regulations — Outcomes of Pilot Tests and Waivers

This section of the report cites four recent studies concerning the safety and crash experience of motor carriers and drivers granted various waivers from hours-of-service regulations. The first is a simulator-based study; the others are reports from pilot tests and operational waivers from intrastate hours-of-service regulations.

O'Neill, T.R., Krueger, G.P., & Van Hemel, S.B. (1999). ***Effects of Operating Practices on Driver Alertness.*** **Report No. FHWA-MC-99-140) Washington, DC: Federal Highway Administration.**

This study was performed to assess the interactions between several trucking industry operating practices and driver fatigue-related performance decrements. The activities studied were: loading and unloading freight; the amount of non-duty time ("rest and recovery") required to reestablish baseline fitness for duty at the end of a multiday series of workshifts; and a sustained schedule consisting of 14 hours on-duty and driving time followed by 10 hours off-duty.

The study design included two days of orientation; five 14-hour days followed by 58 hours off; five more 14-hour days and a second 58-hour period off; and a final 14 hour day. The 14-hour duty periods began at 7:00 a.m. and concluded at 9:00 p.m. and included three scheduled breaks totaling approximately two hours. The first group of drivers operated a driving simulator during their first five-day study period; during the second five-day period, they operated the driving simulator and also performed a physical loading task. The second group did the driving and physical loading task the first week and the driving task the second. Both groups performed the driving task the last day of their participation. The driving task was performed on a high-fidelity fixed-base driving simulator. The loading/unloading task required the drivers to carry 32 19.5 kg (43 lb) cartons six meters from one pallet to another, then move the pallet with a pallet jack.

Data collected from the simulator operation included vehicle-control variables, responses to traffic situations, and probed performance indicators. Physiological recovery was measured via sleep latency tests performed after the fifth day of the duty cycle and during the "weekend" 58-hour recovery period.

The researchers reported the following results. Effects of loading and unloading on alertness and performance were mixed: performance improved after morning sessions but sessions later in the workday appeared to intensify time-of-day and time-on-task effects. The drivers did not appear to have accumulated significant sleep loss during the study but their amount of measured sleep increased and their sleep latency decreased on their first off-duty days. The researchers suggest that: *the effectiveness of a full two nights and one day off (that is, "Friday night" to "Sunday morning" as a minimum safe restart period — about 32 hours off duty) under the conditions tested.* (p. 48) Finally, they noted that the data indicated a slight but statistically significant deterioration in subjective sleepiness, psychomotor vigilance response, and other [objective] measures, but that performance on probe tests did not show cumulative deterioration.

Reviewer's Notes: The study design provided a relatively benign schedule that provided 10 consecutive hours off-duty and also allowed the drivers to sleep at times most compatible with circadian rhythms. The end-of-week recovery periods allowed three sleep periods that allowed sleep during optimal times — between midnight and 6:00 a.m. The duty days also included three scheduled breaks. As the researchers note, the results of this study may not be generalizable to operations that are not day shifts, have shorter post-shift off-duty periods, have few or no breaks during the duty period, or vary from what the driver is accustomed to in terms of circadian disruptions or longer-than-usual on-duty periods.

Office of Motor Carrier Safety and Compliance (March 1992). *A Report to the Minnesota Legislature: a Study of the Effects of Exempting Fertilizer and Agricultural Chemical Retailers from Driver Hours-of-Service Regulations.* (Available from the Minnesota Department of Transportation).

In 1990, the Minnesota legislature requested the Minnesota Department of Transportation (MnDOT) to study the effects of exempting fertilizer and agricultural chemical retailers and their employees from driver hours of service. That year, the legislature had exempted retailers of agricultural chemicals and fertilizer from the hours-of-service regulations when agricultural chemical deliveries were made directly to a farm within 50 miles from the retail plant.

MnDOT conducted a mail survey of agricultural chemical dealers during the spring and summer of 1991. The agency also conducted a focus group of these dealers and collected information on their operations, driver hours of service, and agriculturally-related hazardous material chemical spills.

Information from the survey included the following: Nearly three-quarters of the vehicles used in these operations are 2-axle vehicles, mainly pickup trucks. The spring [planting] season starts around April 15 and lasts 34 to 53 days depending on weather; delivery hours typically begin about 7:00 a.m. and run until 6:00 p.m. or later; about 40 percent of reported agricultural-related hazardous materials spills occur in April, May, and June, with half of those spills occurring in May.

Information obtained from the focus groups included the following: the average round-trip was 21.7 miles, and the average driver's daily duty time was 12.6 hours. The vast majority of travel was on county and State roads — Interstate highways accounted for less than 1 percent of the recorded travel mileage.

The report concluded: *Exempting ag-chemical retailers from hours of service rules is not consistent with federal initiatives for uniformity in motor carrier safety laws. However, ag-chemical retailers represent a concentrated population, subject to most motor carrier safety regulations. Farmers, on the other hand, are an extremely dispersed population, exempt from many hazardous material motor carrier regulations. To the extent that an hours of service exemption will encourage the handling and delivery of fertilizers and chemicals by trained personnel, then such an exemption may be in the interest of safety. Should the legislature decide to grant an hours-of-service exemption to ag-chemical retailers, however, it should be crafted so it does not extend to other businesses or industries.* (p. ii)

California Highway Patrol (May 1996). ***California 1995 Drivers' Hours of Service Waiver and Exemption Period for Specified Farm Products and Products of Preservation.*** **Sacramento, California: Enforcement Services Division Department of California Highway Patrol.**

Under provisions of the California Code of Regulations, the California Highway Patrol (CHP) granted limited waiver of driver hours-of-service for drivers transporting grapes, tomatoes, and apples. The CHP also granted a waiver for drivers transporting products of preservation (cans, boxes, plastic wrapping, etc.) for processing the produce. Thirty-three motor carriers requested and were granted waivers. The waivers and exemptions were valid from August 15 through October 31, 1995.

The waiver allowed drivers to operate for 28 consecutive days on a schedule that included up to 12 hours driving during a 16-hour work period. They could then take 24 consecutive hours off duty and operate for a second 28 consecutive day period. Under normal conditions, drivers operating in intrastate commerce in California can drive up to 12 hours during a 16-hour on-duty period and may be on-duty up to 80 hours in any 8 consecutive days. Under the waiver, the cumulative on-duty time allowed in an 8 consecutive day period was 128 hours.

CHP conducted post-waiver audits of these motor carriers to evaluate drivers' hours-of-service compliance and the motor carriers' crash experience. The CHP noted that the agency did not collect control data because it would have been very labor-intensive and caused disruption to the control carriers' business. According to the report:

The limited data provided by the post-WEP [Waiver and Exemptions Period] *evaluations does not support a conclusion that the findings represent typical performance of the agricultural transportation industry. Actually, BIT* [Biennial Inspection of Terminals] *Program statistics show that, in general, most carriers are satisfactorily complying with requirements.* (p. iii)

There were 26 accidents resulting in 13 injuries and two fatalities; in 18 of these 26 accidents, the participating truck driver was at fault. Due to widespread falsification of drivers' records of duty status, and instances where carriers and/or drivers failed to maintain or retain required records, the impact on highway safety of providing limited drivers' hours of service waivers and exemptions could not be accurately assessed. (p. iii)

Bowen, V. (1996). ***Utility Service Vehicle Study*****. Richmond, VA: University of Richmond. (see docket number FHWA-97-2350-82)**

This study was performed to assess potential influence of duration of on-duty time (tours of duty) on the accident experience of CMV drivers operating utility service company vehicles. Data was collected from May 1, 1995 through June 30, 1996. Nineteen utility companies participated. Drivers were selected based upon a 10 percent random sample from each company. Both the company and driver pools were dynamic and new driver participants were selected after six months. The 10 percent sample drivers accumulated nearly five million miles of driving. Companies were a mix of FMCSR-regulated and non-regulated public utilities.

Ninety crashes were reported, resulting in a crash rate of 18 crashes per million vehicle miles. The author states: *Based on this limited exposure* [1731 hours of driving time reported], *it seems that after 80 hours on duty* [in a 7 day period], *the accident rate rises precipitously.*" (p. 15)

Reviewer's Notes: Although the study tracked exposure by both driving time and distance, there were no statistics presented aside from purely descriptive graphs and tables. No significance tests were discussed. No baseline data was presented. This is a concern given the extremely high reported crash rate. The data was not analyzed to assess time-of-day effects. The author did not report the highway classes where the travel took place and this factor was not used to discriminate among portions of the data.

Hours-of-Service Regulations, Operational and Performance Models

A number of researchers and practitioners have recommended issues for transportation operators, policymakers and regulatory agencies to consider when developing schedules and hours-of-service regulations. Many compelling arguments reflect the influence of sleep, or the lack thereof, on a transportation vehicle operator's (or other worker's) alertness and the effect a lack of alertness and lowered level of situational awareness can have on safe and efficient operations. Others make a case for flexibility in setting regulatory minima and maxima to reflect variations in the types of operations subject to the regulations and the variability among individuals' vulnerability to loss-of-alertness.

Mitler, M., and Miller, J. (1996). Some Practical Considerations and Policy Implications of Studies of Sleep Patterns. *Behavioral Medicine 21*, 184-185.

The authors introduce their paper as follows: *Among the most challenging public-policy issues are (a) the rate and temporal distribution of human error catastrophes that should be considered unavoidable and normal, (b) the degree to which a person's sleep tendency must rise before it is considered a risk to the person or to the public, and (c) the extent to which human error caused by abnormal or normal levels of sleepiness can be reduced.* (p. 184)

The authors discuss several aspects concerning recognition of the problem of sleep patterns and operator alertness: the amount of potential and kinetic energy a typical worker controls now compared to what was controlled in the 19th century; the impossibility of assigning nightwork; weakness in design of jobs and systems requiring a human-operator; and the lack of transferability of [laboratory-based] sleepines-recognition tools to the workplace. They cite work by Rosekind and his colleagues for recommendations to integrate principles of sleep research and human factors to the redesign of jobs and staffing schedules.

Åkerstedt, T. (1997) Readily Available Countermeasures Against Operator Fatigue. In *Managing Fatigue in Transportation.* Rockville, MD: Government Institutes, Inc., 105-120.

The theme of this conference paper centers upon available and potentially-available methods that workers with irregular schedules can use to avoid or minimize sleepiness. The author cites Dement's and Carskadon's finding that sleepiness reflects the level of activation of the central nervous system deactivation. Therefore, the countermeasures they present focus on avoiding the deactivating situations and seeking activating ones.

Dr. Åkerstedt provides an extensive summary of summaries citing decrements in physiological state, task performance, and subjective assessments associated with lowered levels of alertness during night shifts and irregular shifts. He cites four reasons for this condition: desynchronization of circadian rhythms, short sleep, time awake (particularly over several days), and external stimulation. He then discusses countermeasures to address each. He notes that phase shifting via bright light exposure or administration of melatonin is the subject of considerable research but neither has been sufficiently evaluated to recommend for use on a long-term basis or in an operational environment.

Dr. Åkerstedt believes that work schedules may be improved by allowing sufficient time between shifts and between shift changes for recuperative sleep. Schedule setting should consider the number of consecutive night work periods; the speed of shift rotation (rapid rotation seems to be better); the direction of shift rotation (clockwise rotations are better tolerated); and the length of the work period (time-on-task effects).

In the categories of activities to increase central nervous system activation, the outcomes have generally not been as thoroughly studied and some cannot be clearly differentiated. For example, breaks alone or breaks including food intake or other activities. He includes in this family of countermeasures physical activity, including social interaction, breaks, food intake, and increased environmental stimulation through increased sound levels, reduced temperature, increased lighting, and improved ventilation. Dr. Åkerstedt emphasizes that the effects of these countermeasures are temporary, generally last only while the stimulation is applied, and that some are unpleasant (sound and temperature) and would likely not be acceptable to users.

Rosekind, M.R., Neri, D.F., & Dinges, D.F. (1997). From Laboratory to Flightdeck: Promoting Operational Alertness. *Fatigue and Duty Time Limitations — An International Review.* London: The Royal Aeronautical Society. pp. 7.1-7.14

This paper provides a very broad overview of scientific and operational perspectives in the context of developing hours-of-service regulations for pilots as one tool to promote and maintain aviation safety. The authors begin with a discussion of human sleep requirements, the effects of sleep loss on human performance, and the circadian clock. They describe selected studies of accident cases (National Transportation Safety Board studies) and critical operational performance failures (*Challenger* Accident and others) where sleep loss combined with circadian factors were considered to contribute to the negative outcomes.

The authors offer several recommendations for consideration in developing operational guidelines:

- Establish a *minimum rest period* providing for 8 hours of sleep opportunity every 24 hours.

- Consider the *time period of continuous wakefulness*, particularly if a shift is contemplated that lasts 12 or more hours.

- Consider *circadian troughs* (3:00 a.m. to 5:00 a.m. and midnight to 6:00 a.m.) associated with significant alertness and performance degradation and increases in operator error and in accidents. *The stability of performance during a 14 hour daytime duty period is not the same as during a 14 hour nighttime duty period.* (p. 7.6). Consider also the effect of time zone changes.

- Consider *cumulative fatigue effects. It is important to maintain an optimal sleep opportunity every 24 hours and also address the potential for cumulative effects. Therefore, appropriate recovery time should be allowed per week (days or rolling hours). Scientific studies show that two nights of recovery sleep are typically needed to resume baseline levels of sleep structure and waking performance and alertness.* (p. 7.6).

The authors close by advising that regulations on flight, duty, and rest hours are only one component necessary to address fatigue in an aviation environment and that education and air carrier-based alertness management programs would also play an important role. They cite a cooperative agreement with the New Zealand Civil Aviation Authority which included an operational field study with Air New Zealand as an example of a successful operationally-based program.

Wegmann, H., Hasenclever, S., Michel, C., & Trumbach, S. (1985). Models to Predict Operational Loads of Flight Schedules. ***Aviation, Space, and Environmental Medicine 56:*** **27-32. Washington, DC: Aerospace Medical Association.**

The authors assess models of physiological loading developed by others and present a new one. The models "attempt to quantify factors which are considered to constitute the operational load of flight schedules: flight duty time, night duty, time zones, arrival and departure time, duration of layovers, days away from home base, and accumulated duty hours" (p. 27).

The new model the authors developed and planned to test and evaluate included five factors: flight duty time, night duty hours (1:00 a.m. to 7:00 a.m. local time), number of transits, preceding layover time, and time zones crossed during preceding flight leg. They assigned coefficients based upon the expected physiological loading. A computed "workload index" placed a flight in a category of "normal," "severe," or "definitely severe." The authors stated the model needed to be tested in practice to determine whether it overestimated workload under certain conditions.

Reviewer's Note: This study presents a novel approach. It would be worthwhile to see if similar work has been done in land transportation.

Fletcher, A. and Dawson, D. (1997). Cabin Safety and Hours of Work: Developing a General Risk-control Model for Fatigue. ***J. Centre for Sleep Research 2,*** **pp. 9-26.**

The researchers developed a simple algebraic model to illustrate potential for operator fatigue under different types of schedules. They considered the durations of work and non-work periods and weight fatigue "accumulation" and "recovery" functions according to circadian timing. The model also weights work- and non-work periods differentially to give more weight to those in the recent past and caps the amount of fatigue reduction that can be obtained during recovery periods. The researchers note their model does not account for differences among individuals nor differences between circadian and clock time.

The authors illustrate model outputs to compare "fatigue scores" arising from a variety of schedule comparisons. They compare these scores to those computed from a "standard"

Monday-Friday 9:00 a.m. to 5:00 p.m. workweek and rate them as standard (within 0-100 percent), moderate (100-200 percent), or severe (greater than 200 percent).

Reviewer's Notes: Although the model is attractive in its simplicity, there are more sophisticated and comprehensive models such as those developed by Åkerstedt, et al. and others being developed at the Walter Reed Army Institute of Research. These models more precisely model the recovery effects of long and short sleep periods, and account for the circadian rhythmicity that Fletcher and Dawson note as a limitation in their model.

Lin, T., Jovanis, P., & Yang, C. (1993). Modeling the Safety of Driver Service Hours Using Time-Dependent Logistic Regression. *Transportation Research Record 1407.* pp. 1-10. Washington, DC: Transportation Research Board.

This research continues earlier work by Jovanis, et al. to estimate the probability of a crash at a given driving time interval. The authors' obtained their data from the same nationwide less-than-truckload motor carrier that was the subject of their earlier studies. They tested the following covariates: consecutive driving time, multiday driving patterns over a seven-day period that included time of day of driving and days driving within that period, driver age, driving experience, and hours off-duty prior to the trip. The authors generated ten clusters of driving patterns.

The driving pattern with the lowest risk was "Pattern 2," described as a highly regular schedule with on-duty times generally spanning the period 6:00 a.m. to about 2:00 p.m. and off-duty times generally spanning the period 6:00 p.m. to 4:00 a.m. Risk in six other schedule patterns that included night and very early morning driving, morning and evening rush-hour driving, and very infrequent scheduled driving had computed crash risk about 1.5 times as high (p. 5). When off-duty hours were assessed, the risk for off-duty periods less than or equal to 9 hours was 1.4 times higher.

When driving time was the category of interest, there was no statistically significant differences among the first four hours but the ratio increased from that time until the last driving hour. The authors noted a limitation in their analysis, and provide a caveat to the estimates of the odds ratios in the last driving hour category: a large number of non-crash trips are completed during the 8th or 9th hour of driving, but the authors' "assumed failure time," defined as the expected time of involvement in an accident, would occur after this trip completion time. (p. 5)

Saccomanno, F.F., Craig, L.V., & Shortreed, J.H. (1997.) Multi-Stakeholder Perspectives on Truck Safety: Results of a Conference on Truck Safety — Perceptions and Reality. (Manuscript Preprint No. 970044) Washington, DC: Transportation Research Board.

The paper summarizes major findings and recommendations from a multi-stakeholder Canadian conference on truck safety issues. The key concerns identified included driver training and empowerment, driver fatigue, data, vehicle brakes and maintenance standards, and harmonization of standards and regulations throughout North America.

Concerning driver fatigue, *The groups felt that current hours-of-service regulations are too narrowly focused to reduce the incidence of driver fatigue in truck accidents. There is a need to establish a comprehensive set of standards that reflect all types of driver fatigue for different driving situations. The groups also felt that low driver wages and lack of empowerment compelled drivers to drive longer hours without necessary rest.* (p. 7)

The conferees recommended support for basic research to better understand driver fatigue under different driving situations. They recommended establishment of tolerance levels for fatigue and accident risk and development of new regulations reflecting those levels. Finally, they urge governments throughout North America to harmonize their [hours-of-service] standards.

Moore, B. & Moore, J. (1996). Prescriptive Driving Hours: the Credibility Gap. ***(Paper presented at the Second International Conference on Fatigue and Transportation,*** **Fremantle, Western Australia. (Manuscript available from authors)**

The authors of this paper question the basis for prescriptive regulation of driving hours as a method to promote improvements in road safety. Based upon what they consider ambiguous and limited findings from studies on crash risk and experience, they authors question the fundamental linkage between fatigue, regulated driving hours, and truck crashes. They said: *It would appear that the prescriptive regulation of driving hours is used, not as a result of a careful assessment of its potential effectiveness in controlling fatigue, but because of a feeling that something needs to be done and a belief that no other approach is feasible.* (p. 7)

The authors raised concerns about the application of a single standard for driving limits, given the potential for anomalies and inequitable application of the regulation. They questioned the usefulness of tools and records currently in place to determine compliance with the regulations, whether the records are required by law or self-generated by the motor carrier. They also raised concerns about uneven regulatory enforcement adversely impacting the competitive position of law-abiding motor carriers and a mismatch between trip lengths and customer needs and prescriptive regulations.

Moore and Moore promote an approach to fatigue management stressing drivers' preparation for driving long hours by obtaining adequate sleep prior to making a trip. They refer to an arrangement promoted by motor carriers operating in remote areas of Australia that utilizes cycles of several days in length and that includes long breaks between the work cycles. They also note that management commitment is critical in terms of driver selection and support. Finally, they recommend research to compare safety outcomes of locations under prescriptive regulatory regimes to those with unregulated hours-of-service.

Reviewer's Notes: This paper presents an important point of view concerning the effectiveness of prescriptive regulations. Although many aspects of the Australian motor carrier industry and highway environments are distinctly different from those in North America, this paper raises some important fundamental issues. The authors do not advocate total deregulation of driving hours. They do point out limitations in the application and enforcement of hours-of-service regulations, as they noted: *It must be expected that many operators have concentrated on compliance with the letter of the law and production of plausible log books rather than management of fatigue among their drivers*. (p. 18).

It also is possible that the authors may have been selective in some of the data and statistics they used. For example, the New South Wales data on fatigue-related crashes is limited to injury crashes. They did not report what the fatal-crash trends were. Also, the discussion of the California hours-of-service pilot program quoted an article from a motor-carrier industry magazine. The discussion in the California Highway Patrol's study report, the reference cited in this synopsis, was somewhat different.

Technological Approaches to CMV Driver Alertness Management

The studies in this final section focus on current and potential uses of technological tools for CMV driver alertness management. The first three studies discuss the current use, and caveats and concerns regarding expanded use, or electronic on-bord recording systems for recording of drivers' hours of service; issues concerning user acceptance of intelligent transportation systems (ITS) commercial vehicle operations services; and an assessment of the use of smart cards in these operations. The final two articles provide an overview of tools and techniques to test and assess sleepiness and recommendations to gauge the validity of technological aids from technical, operational, and policy perspectives.

Campbell, K.L., Lang, S. L., & Smith, M.C. (1998). ***Electronic Recorder Study.*** **Report No. UMTRI-97-34. Ann Arbor: University of Michigan Transportation Research Institute.**

(Authors' Abstract:) *Information on the current use of electronic recorders, and opinions on mandatory electronic recorder use, was obtained from truck and bus fleets and owner-operators through the cooperation of several trucking industry associations. This study does not address the relationship of electronic recorders (ERs) to compliance with the hours-of-service (HOS) regulations, nor the relationship of compliance with HOS to fatigue or safety.*

Due to the low response rate (12 percent), the results cannot be considered as representative of the larger populations of fleets and trucks. One-third or more of responding National Private Truck Council (NPTC) members, and large private and for-hire fleets used electronic recorders, although only about half were equipped with the HOS function. There is a clear pattern, evident in the responses received and the 1992 Truck Inventory and Use Survey (TIUS) data, of increasing ER use with larger fleets. ER use ranges from zero to only a few percent in small truck fleets, among owner-operators, and in bus [motorcoach] fleets.

[Estimates obtained from users indicated that] *use of ERs to maintain HOS records saved drivers 20 minutes per day in comparison to paper logbooks, based on the median difference. Administrative personnel saved 20 minutes per driver per month using ERs. These results* *should not be considered representative of the national population due to the low response rate and small sample size.*

The association between fleet size and the use of electronic recorders appears to be an important issue. Based on the 1996 Motor Carrier Management Information System (MCMIS) data, 90 percent of all carriers operate less than 9 trucks. There is no evidence that ERs are cost effective in small fleets. The overwhelming view of fleets of all sizes is that mandatory use of electronic recorders would require an excessive expenditure for minimal benefits (p. iii).

Reviewer's Notes: Five motor carrier industry associations (National Private Truck Council, Owner Operator Independent Drivers Association, Independent Truck Drivers Association, American Bus Association, and United Motorcoach Association) agreed to participate in this study. However, the American Trucking Associations declined to participate. The FHWA provided the University of Michigan Transportation Research Institute with Motor Carrier Management Information System (MCMIS) Census File listings of motor carriers with interstate operating authority in order to develop additional lists of large, medium, and small motor carriers in the for-hire and private fleet categories. The response rates by group were considerably lower than the researchers had projected, and ranged from 3.1 percent to 8.4 percent for the motor carriers lists generated from the MCMIS files. By contrast, the response rates from the five industry associations' lists varied from 15.3 percent to 24.4 percent.

Penn + Schoen Associates, Inc. (1995). *Critical Issues Relating to Acceptance of CVO Services by Interstate Truck and Bus Drivers.* (Draft final report. Contract No. DTFH61-94-C-00182.) Washington, DC: Federal Highway Administration. (See Docket number FHWA-97-2350-426.)

Data for this study was collected from 1582 interviews (1,134 in-person interviews with truck drivers, 411 in-person interviews with motorcoach drivers, and 37 telephone interviews with participants in Commercial Vehicle Operations (CVO) operational tests). Drivers were asked their opinions on six existing and evolving CVO services: fleet management, electronic clearance, administrative processes, roadside safety inspection, hazardous materials incidence response, and on-board safety monitoring. They were asked to assess the services according to 13 attributes such as usefulness, safety improvement, reduction of traffic congestion, making work easier, invasion of privacy, regulatory compliance, and reliability. The following is taken from the executive summary:

> *This study of CVO Services shows that, on the whole, commercial vehicle drivers are receptive to and supportive of the use of CVO service on the road and in their vehicles. Technologies which received the most support were those that would "make my work easier," are "useful for me,' and "will work [in my vehicle] / I would rely on it."* (p. 9)
>
> *However, there was some concern that certain of the technologies would be an invasion of driver privacy by either the government or the driver's company, and also a concern that the systems would rely too much on computers and diminish the role of human judgment. Drivers were wary of services that promised too much and would leave them dependent on unproven, inexperienced technology. They wanted systems that would be reliable, workable, and useful on a consistent basis, and would not pose a threat to themselves, their vehicles, their privacy, or their livelihood.* (p. 9).
>
> *On the whole, drivers tended to evaluate the CVO services from the perspective of their personal experience, rather than focusing on the bigger picture of the industry as a whole. For example, independent owner operators, who have historically been more skeptical of technology and wary of intrusion by the government or companies, reacted more negatively toward the technologies than did other drivers . . . In particular, there were significant differences among the following groups: union vs non-union drivers; company drivers vs independent owner operators; younger vs older drivers; newer drivers vs drivers who have been driving for many years; truck drivers vs bus drivers.* (p. 9)

In general, drivers were less favorably inclined towards the onboard safety monitoring service than the other CVO services. The report states: *While a majority of respondents were able to recognize the potential safety benefits of this service, the idea that the technology was* *too invasive and too reliant on computers made some respondents unwilling to accept this service.* (p. 22)

3-G International (1996). ***Smart Cards in Commercial Vehicle Operations.*** **(Report No. FHWA-MC-97-022). Washington, DC: Federal Highway Administration. (NTIS No. PB97-130504); (See Docket Number FHWA-97-2350-616).**

This study responded to Congressional direction to the Federal Highway Administration contained in the fiscal year 1995 appropriations bill for the U.S. Department of Transportation . . . *test the feasibility of a smart [card] system to enhance the security and utility of the commercial driver's license and enforcement of hours-of-service regulations.* (p. i, citing House of Representatives Report 103-752 at 48, Fiscal Year 1995 *Appropriations for Department of Transportation and Related Agencies.*) Smart cards, for the purposes of this study, were defined as a credit card-sized plastic card with an embedded integrated circuit chip containing a central processing unit, random access memory, and non-volatile data storage. The researchers assessed technological, economic, and institutional factors requiring consideration if smart-card applications were to be implemented.

The researchers determined that three smart-card applications were feasible: driver's license, vehicle card (for operating credentials and maintenance purposes), and electronic toll collection. Two were determined to not be feasible: international border crossing because data transfer via telecommunications already is in place under the U.S. Customs Service and driver record of duty status. The researchers noted three obstacles to implementing the latter:

> *Current federal regulations do not require motor carriers to automate the Driver Record of Duty Status. Any proposed regulation specifying the use of smart cards would almost certainly encounter fierce opposition.* (p. 51)

> *All ITS programs are voluntary, and the federal government would jeopardize carrier participation in other ITS activities if it tried to mandate the use of smart cards.* (p. 51)

> *Smart cards and readers, though durable, can be rendered inoperable through abuse. Inspectors would have many implementation issues to address to create a workable system.* (p. 51)

Reviewer's Note: The Fair Information Principles for ITS/CVO approved by the ITS America Board of Directors on April 22, 1999 include a "secondary use" provision as follows: *Data collected by the private sector for its own purposes through a voluntary investment in technology over and above those data required by law should not be used for enforcement purposes without the carrier's consent.*

Mitler, M., & Miller, J. (1996). Methods of Testing for Sleepiness. *Behavioral Medicine 21*, pp. 171-183.

This paper provides a summary and commentary on the two-peak temporal pattern of peaks in performance and human error, and a variety of objective and subjective methods to assess alertness. The authors include discussions on EEG monitoring of sleep, sleep disorders, and sleep tendency; subjective self-reporting (Stanford and Epworth Sleepiness Scales); pupillography; EEG-based techniques (Multiple Sleep Latency Test and Maintenance of Wakefulness Test), and emerging techniques in computerized analyses of EEG data. The authors describe predictive mathematical modeling of sleep- and performance-related data to curves based upon a population-based function and the cosine function. They pay particular attention to the role of sleep deprivation in the development of the model. They fit an idealized curve to 6 data sets involving different outcomes (accidents, mortality, driver drowsiness, communication operators' delay in answering calls, locomotive engineer braking, and utility-meter reading errors) that include several different phase lags (hours past midnight) and sleep deprivation factors.

Reviewer's Notes: Several other researchers have or are currently collecting and using empirical data to develop and validate numerical models of alertness and drowsiness tendency by time of day and over multiday periods. This is one of the basic cornerstones of models such as the Sleep-Dose Response model being developed at the Walter Reed Army Institute of Research for use in the Actigraph.

Dinges, David F. (1997). The Promise and Challenges of Technologies for Monitoring Operator Vigilance. In *International Conference on Managing Fatigue in Transportation*. pp. 77-86. Rockville, MD: Government Institutes, Inc.

In this conference paper, Dr. Dinges expresses concern that major issues exist concerning the identification, development, and setting of standards in the quest for developing technological approaches to managing transportation operator fatigue and vigilance. Dinges offers three sets of criteria to gauge the performance of these technological aids:

- Scientific/engineering: validity, reliability, generalizability, sensitivity, specificity.
- Practical/implementation: ease of use, acceptance by target population, unobtrusiveness, robustness, economical, implementation.
- Legal/policy: purpose, mandatory nature; privacy, enforcement, misuse potential, liability.

Dinges classifies operator-centered technologies according to environment (operator-, system-, and environment-centered); risks/impairments claimed to be detected; and vulnerability to error based upon on-line monitoring or performance probes. He describes advantages and disadvantages of technologies designed to monitor vehicle-based performance, readiness-to-perform/fitness-for-duty, and vehicle-based alertness/drowsiness/vigilance. He notes that various types of biobehavioral measures have been applied to these technologies but points out that there is a lack of real-world validation of laboratory results and that many equipment developers' claims concerning the efficacy of the technologies have not been scientifically validated. Finally, he discusses mathematical models for designing work/rest schedules or monitoring operators' alertness. He cautions that, although the models themselves are becoming increasingly accurate, their precision and validation is still lacking.

Dr. Dinges closes: *Technologies may eventually prevent or limit certain catastrophic outcomes due to fatigued performance, but technologies are not substitutes for setting societal standards for the functional capability of an operator. On the other hand, technologies can help establish and maintain adherence to that standard if they are developed and used in a valid and responsible manner.* (p. 83)

Author/Title Index

Appendix to Preamble for FHWA Docket No. MC–96–28 RIN 2125–AD

A. Research Into the HOS of Drivers

Copies of all research reports mentioned below are included in the FHWA docket, number MC–96–28, and will be available for examination. In addition to comments and research reports received in response to this notice, the FHWA will also continue to file in the docket other research reports that become available after the publication of this document. Interested persons should continue to examine the docket for new material.

Prior Research

The first scientific study which addressed the HOS of U.S. commercial drivers was performed in the late 1930's. On April 25, 1938, the ICC requested the United States Public Heath Service (USPHS) to conduct an investigation into the problem of fatigue and HOS of drivers of commercial motor vehicles operating in interstate commerce. See *Fatigue and Hours of Service of Interstate Truck Drivers*, U.S. Public Health Service, Washington, D.C., Public Health Bulletin No. 265, 1941. The USPHS found that "it would * * * appear that a reasonable limitation of the HOS would, at the very least, reduce the number of drivers on the road with very low functional efficiency. This, it might reasonably be inferred, would act in the interest of highway safety." Although the ICC indicated the need for further study, no further study was undertaken by USPHS or the ICC.

In the 1970's, the FHWA and its sister agency, the National Highway Traffic Safety Administration (NHTSA), conducted three studies which investigated driver performance and fatigue. They are reported in:

1. William Harris, et al. Human Factors Research, Inc., "A Study of the Relationships Among Fatigue, HOS, and Safety of Operations of Truck and Bus Drivers," (Springfield, VA, National Technical Information Service, 1972, (PB–213 963)). The general findings of the study indicated that driver performance deteriorates, driver alertness (as reflected in psychophysiological arousal) diminishes, rest breaks become less effective, and accident probability increases, all within the 1972 10-hour daily limitation on driving time. The study also concluded that the situation would likely remain as long as drivers are rewarded economically in direct proportion to the amount of time spent on the highway.

2. Mackie, R.R., O'Hanlon, J.P., and McCauley M., Human Factors Research, Inc. "A Study of Heat, Noise, and Vibration in Relation to Driver Performance and Physiological Status," December 1974. This study measured the stressful effects of heat, noise, and vibration on the physiological status, feelings of alertness and fatigue, and actual driving performance of automobile and truck drivers under realistic conditions. The research found that heat and humidity between 80 and 85 degrees Farenheit WetBulb-Globe-Temperature (WBGT) index had somewhat adverse, but less dramatic,

effects on driver physiology and level of arousal for professional truck drivers than nonprofessional drivers. The WBGT is an index reflecting the combined effects of air temperature, air velocity, and relative humidity. The study's findings also indicated that the levels of fatigue and central nervous system arousal experienced by drivers were not systematically different for the different noise-vibration condition encountered.

3. Mackie, Robert R., and Miller, James C., Human Factors Research, Inc., "Effects of HOS Regularity of Schedules, and Cargo Loading on Truck and Bus Driver Fatigue," (Springfield, VA, National Technical Information Service, 1978 (PB–290–957)). The study's findings indicated 18 main points, including that: (a) Some cumulative fatigue occurs during 6 consecutive days of relay operations, but time of day strongly affects how much will be seen; (b) participation in moderately heavy cargo loading to the extent engaged in by many relay truck drivers increases the severity of fatigue associated with irregular schedules; (c) sleeper driver fatigue, physiological state, and performance are strongly affected by time of day; (d) bus drivers operating on irregular schedules suffer greater subjective fatigue and physiological stress than drivers on a regular schedule; and (e) the major problem posed by irregular operations is that the driver must at some time drive during those hours of the night when circadian depressions in psychophysiological arousal are substantial.

The U.S. Army Research Institute for the Behavioral and Social Sciences' "Prolonged Heavy Vehicle Driving Performance: Effects of Unpredictable Shift Onset and Duration and Convoy Versus Independent Driving Conditions" (September 1983, Technical Report 585) found that the effects of prolonged driving depend in part on *when* that prolonged driving takes place, rather than simply on the prolonged driving's actual *duration.* This was an empirical, field experiment that used twelve Army truck drivers in experimental trucks in a continuous convoy on four consecutive days on a pre-selected 300-mile route. The report notes that feelings of fatigue, overall, did not show dramatic change over time, although a trend was noticed in the pattern of performance deterioration toward the end of the late shift for drowsiness, exhaustion, and awareness-daydreaming-hallucinations. The conclusion was that it is the timing, and not the duration of the late shift, that makes driving more fatiguing.

In 1985, the American Automobile Association's (AAA) Foundation for Traffic Safety in "A Report on the Determination and Evaluation of the Role of Fatigue in Heavy Truck Accidents," examined about 250 accident reports of heavy truck accidents in six Western States. The study looked specifically at the driver's pre-accident activities and attempted to determine whether fatigue was a primary or probable cause of the accident. The study concluded that fatigue was the probable or primary cause of 41% of those heavy truck accidents.

In 1987, the Congressional Office of Technology Assessment's (OTA) report, "Gearing Up For Safety," concluded that aggressive Federal research programs addressing fatigue and sleep issues and determining their role in truck accidents should be top priorities. The report also concluded that the FHWA should reexamine the HOS regulations, and develop revised standards based upon current knowledge.

This same OTA report noted that in the Insurance Institute for Highway Safety's "Sleeper Berth Use as Risk Factor for Tractor-Trailer Driver Fatality," evaluated the association of sleeper berth use in two periods and tractor-trailer driver fatalities. The study found that sleeper berth use increased the risk of fatality more than twofold. Night driving was also found to significantly increase the risk of truck driver fatality.

In February 1988, the Insurance Institute for Highway Safety in "Tractor-Trailer Driver Fatality: The Role of Nonconsecutive Rest In A Sleeper Berth," revised its earlier study of the association of sleeper berth use and tractor-trailer driver fatalities. The revised study found that sleeper berth use increased the risk of fatality more than threefold, not twofold as originally reported to Congress' OTA.

In June 1988, the Australia Transport and Communications' (ATC) Federal Office of Road Safety in "Driver Fatigue: Concepts, Measurement and Crash Countermeasures" (Report No. CR 72) reviewed the concepts and theories directly related to fatigue, the measurement of fatigue, and factors contributing to the onset and development of fatigue. Also reviewed was the degree to which fatigue is associated with road crashes, countermeasures having potential for offsetting the degrading effects of fatigue on safety, and an identification of research issues having promise for reducing the role of fatigue in crashes.

On November 29–30, 1988, the FHWA sponsored a symposium on truck and bus driver fatigue. Researchers in the area of fatigue and data collection attended, along with motor carrier participants. The primary purpose of this symposium was to identify research that was needed in the area of driver fatigue.

The DOT, in "Transportation-Related Sleep Research" (March 1989), reported to the Congress about the Department's actions in researching sleep and its effects on transportation safety. The report gave special emphasis to the efforts of NHTSA and FHWA related to the truck and bus industries. The discussion included the FHWA-sponsored symposium, past commercial driver fatigue- and alertness-related research, and future research to be undertaken.

The Institut National de Recherche sur les Transportes et Leur Securite's (INRETS) report, "Working Conditions of Drivers in Road Transport," (October 1989, ACTES INRETS No. 23) presented twelve research discussion abstracts written by various researchers from Canada, France, Germany, Ireland, Sweden, Netherlands, and the United Kingdom at a conference in France on June 3 and 4, 1988. Topics included "Sleepiness at Work: Measurement and Regulation," "Reviewing Fatigue and Driving," "Disposition of Waiting Time and the Waiting Behaviour of Truck-drivers," "Working Hours of European International Truck-Drivers," "Know-how in the Management of Working-Time and Safety," "Medical Survey of French Truck-Drivers: a Cross-sectional Study of the Most Frequent Pathologies," "Problem-Study of the Work of Heavy-goods Drivers in Quebec: Work Accomplished and Future Prospects," and "Regulations in Seven E.E.C. Countries Concerning Work Duration of Long Distance Lorry Drivers."

The NTSB published a study in February 1990, of 182 fatal-to-the-CMV-driver heavy truck accidents in eight States resulting in 207 fatalities. The NTSB's accident investigations considered the presence of fatigue, alcohol and other drugs, and medical factors involved in these accidents. Fatigue was implicated as a causal factor in 31 percent of these accidents.

The ATC's "NSW (New South Wales) Heavy Vehicle Crash Study Final Technical Report" (August 1990, Report No. CR 92 (FORS), CR 5/90 (RSB)) concluded that "heavy vehicle driver fatigue is clearly an important issue * * * in at least 14 percent of (Australian) heavy vehicle crashes." The report indicated that the regulations should recognize that there are factors other than just the period of time at the wheel of the heavy vehicle that are important.

The FHWA's "HOS Study: Report to Congress" in November 1990, reported on the FHWA's progress in addressing driver fatigue. The report summarized prior research, discussed factors that had been identified with the onset of driver fatigue, and described the FHWA's current research efforts.

The Insurance Institute for Highway Safety's "Who Violates Work Hour Rules: A Survey of Tractor-Trailer Drivers" (January 1992) surveyed long-haul tractor-trailer drivers to estimate what proportion of drivers report that they regularly violate the HOS rules and to identify the drivers most likely to commit HOS violations. The survey found that almost three-fourths of the drivers responding to the survey violated the HOS rules. About two-thirds of the drivers reported that they routinely drive or work more than the allowable weekly maximum. The survey found that the primary impetus for violating the HOS rules appeared to be economic factors, including tight delivery schedules and very low driver earnings per mile rates (less than 30 cents per mile). The study reported many other driver, job, and vehicle characteristics significantly associated with the HOS violator.

The ATC's "Strategies to Combat Fatigue in the Long Distance Road Transport Industry, Stage 1: The Industry Perspective" (May 1992, Report No. CR 108) reported on an effort to gather information about the strategies that would be effective and practical in reducing driver fatigue. The study involved international authorities in the area of fatigue, major employer and employee organizations in Australia, and a questionnaire-based survey of drivers across Australia. The results of the study indicated that shorter trips and greater flexibility in organizing the trip, reducing driving in the early hours of the morning, improving roads, easing schedules, and improving loading and unloading were all factors that were either related to lower levels of fatigue in drivers or were favored by them as ways of managing their fatigue.

The Upper Great Plains Transportation Institute's "Evaluation of the Impact of Changes in the Hours of Service Regulations on Efficiency, Drivers and Safety" (October 1992) surveyed the opinions of five large for-hire motor carriers and their drivers concerning the FHWA's 1992 proposed change to the HOS regulations. The study distributed 3,500 survey forms to these five motor carriers which, in turn, distributed the forms to their drivers. The study received 754 surveys. The study concluded that "[d]rivers, carriers, and society in general would appear to experience positive net gains from a change in the cumulative HOS rules from the current 70-in-8 day rule to a 24-hour restart provision." The study report clearly indicated that the survey was "in no way meant to be represented as a random sample."

The ATC's "Strategies to Combat Fatigue in the Long Distance Road Transport Industry, The Bus and Coach Perspective" (June 1993, Report No. CR 122) is a continuation of the May 1992 report discussed above. This report focuses upon bus and motor coach drivers (the previous report discussed only truck drivers). It also reported that bus and motor coach drivers typically report fatigue before the tenth hour of work, and most commonly in the early hours of the morning.

The Murdoch University Institute for Research into Safety and Transport's "Driver Impairment Fatigue and Driving Simulation: Conference Programme and Proceedings" (September 16–17, 1993, ISBN: 1 86308 014 7) reported on twenty five research projects that were presented at this 1993 conference. The twenty five research papers are included in the docket.

The Society of Automotive Engineers, Inc.'s "Changing Trucking to Match A Changing Work Force" (November 1993, SP–979) included papers on fatigue and sleep deprivation, as well as labor force trends and an overall review of changes that should take place. In "Driver Fatigue and Long Distance Truck Drivers: Implications for Trucking Operations," the author, James C. Miller of Miller Ergonomics, discusses scheduling of over-the-road, commercial trucking operations. He suggests that drivers who have work shifts that end just before dawn, should have their work-rest cycle altered to allow more time to rest during the 24 hours leading up to the end of the work shift. This additional period of time to rest could then be split between additional time for cumulative sleep and the introduction of time for a nap. In Merrill M. Mitler's report on "Sleep Deprivation and Its Consequences for Performance," he recommends five things. His recommendations include: (a) Recognition that present day risks due to fatigue-related human error necessitate accurate cost accounting of human error accidents and effective approaches to risk management; (b) round-the-clock work schedules must be biologically compatible with human sleep requirements; (c) drivers who transport the public or dangerous materials should be tested regularly for their ability to stay awake on the job; (d) people with sleep pathology such as obstuctive sleep apnea and narcolepsy must be identified and treated; and (e) the Federal government must take the lead in formulating new hiring and scheduling guidelines that do not place workers at jobs and on schedules for which they are biologically unsuited.

The University of Tennessee's "Driver-Related Factors Involved with Truck Accidents" (January 1994, STC Project No. 23385–019) study found that fatigue was not specified as a contributing factor in accident reports, but that truck drivers reported that fatigue was a major crash cause.

The ATC's "Strategies to Combat Fatigue in the Long Distance Road Transport Industry, Stage 2: Evaluation of Alternative Work Practices" (September 1994, Report No. CR 144) found that a 12 hour trip was fatiguing for drivers, irrespective of schedule. In particular, driving to a flexible schedule, where rest was taken on a "needs" basis rather than according to the breaks specified in current (Australian) regulations, was found not to be different than driving performance in driver-subjective outcomes. It also did not appear to make a difference whether the trip was "staged" or driven by a single driver. In addition, staged trip drivers were more fatigued at the beginning of the staged trip, compared to the other two trips that they undertook, and remained so at the end of these trips. The study concludes that the effects of accumulated or chronic fatigue may overshadow the effects of acute or short-term fatigue, at least within a 12 hour trip.

The NTSB's January 1995 publication, "Factors That Affect Fatigue in Heavy Truck Accidents," PB95–917001, NTSB/SS–95/01, examined factors believed to influence driver fatigue. Since the study was not meant to be a study of the incidence of fatigue, the NTSB specifically selected truck accidents that were likely to include fatigue-related accidents, such as single-vehicle accidents that occured at night. Based upon its review of 107 accidents, using a multivariate statistical analysis (a multiple discriminant analysis), the NTSB found the most important factors in predicting a fatigue-related accident in its sample to be the duration of the driver's last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep patterns.

The FHWA has also placed in the docket a paper entitled "Management of Fatigue in the Road Transport Industry" which was distributed by the Second International Conference on Fatigue in Transportation at Fremantle, Western Australia (February 1996). The discussion paper states that "over the final two days of the conference, delegates discussed the characteristics of fatigued drivers and what steps could be taken to measure and limit fatigue by Government, the transport industry, and the community who are both drivers and clients of the transport industry." The paper provides recommendations at the conclusion of the discussion of each item.

The ATC's "Strategies to Combat Fatigue in the Long Distance Road Transport Industry, Stage 2: Evaluation of Two-up Operations" (December 1995, Report No. CR 158) suggests that the best strategy to manage fatigue on very long trips may be the judicious use of effective night rest in combination with two-up driving. The study used a regular pre-selected route. The route typically took 100 hours to complete and was a total distance of 4,500 kilometers. The route traversed remote zones. The report concludes that the most effective improvements in managing fatigue must take into account the overall work practices, including activities in the past week, activities before driving begins as well as the way in which the trip is structured.

Current FHWA Research in Relation to Fatigue and Alertness

Driver Fatigue and Alertness Study

The FHWA's motor carrier research and technology program has undertaken research into driver fatigue and loss of alertness. The program incorporates and integrates physiological, psychological, and performance testing technologies. The research began in earnest in 1989, with the award of the baseline "Driver Fatigue and Alertness Study" to the Essex Corporation, Goleta, California, and a companion study of physiological measures of alertness awarded to the Trucking Research Institute (TRI) of the American Trucking Associations Foundation in 1990. For over six years, this massive piece of research has encompassed one of the most technologically and logistically complex field research activities concerning CMV drivers ever conducted—in either the U.S. or the world. This significant piece of research forms the basis for many of the following human factor studies examining driver fatigue and alertness that will be conducted by the FHWA in the years to come.

The FHWA's commercial driver fatigue and alertness effort is being coordinated with the NHTSA and with other DOT operating administrations that support related research on operator alertness, especially the Federal Aviation Administration (FAA) and the Federal Railroad Administration. At the same time, ongoing interaction with the various motor carrier industry associations and drivers" groups continues. These include the TRI, the National Private Truck Council's Private Fleet Management Institute (PFMI), the Owner-Operators Independent Drivers' Association (OOIDA), the Independent Truck Driver's Association, the International Brotherhood of Teamsters, Transport Canada, the Private Motor Truck Council of Canada, and the Canadian Trucking Association.

In 1996, the FHWA will conclude the multi-year, baseline study of Driver Fatigue and Alertness. It has been accomplished with the significant cooperation of five research contractors, two governments (U.S. and Canada), two industry associations, three participating motor carriers, and 80 professional drivers and their management and labor representatives. The overall intent of this research has been to:

1. Provide a technically sound basis for evaluating the current HOS requirements for CMV operators; and

2. Identify potentially effective countermeasures for reducing fatigue and increasing driver alertness.

Through the efforts of these various participants and the combined scientific expertise they offer, the "Driver Fatigue and Alertness Study" has obtained information on a broad range of interrelated items involving the driver/vehicle environment, such as:

1. Driver performance and vehicle operating parameters;
2. Objective and subjective measures of driver psychological and physiological state; and
3. The vehicle operating environment (e.g., cab temperature and air quality).

The TRI has participated with the FHWA in providing assistance to help collect, review, and analyze physiological data from the same driver test subjects. Additionally, the TRI, Transport Canada, and the Canadian Trucking Research Institute have provided financial and on-site assistance to the project.

During the test phase, data were collected through driver field testing for four different driving and operating conditions. A set of field experiments, designed to replicate a range of carrier operations, performed under real world conditions, were undertaken:

1. A "baseline" U.S. operation, consisting of a regular daytime schedule of 10 hours of driving;
2. An "operational" U.S. schedule, which saw driving start and end at different times of the day and night. This schedule was chosen to permit the assessment of a varying schedule set to maximize distance traveled, and yet adhere to the 10-hour driving limit and 8-hour off-duty requirement now in effect;
3. A 13-hour daytime driving schedule operated in Canada which, while longer than the U.S. regulations currently allow, is permitted in certain Canadian provinces. The FHWA was interested in learning if this extended schedule may promote increased driver alertness by keeping the driver's work and rest cycles closer to a 24-hour circadian time table; and
4. A 13-hour nighttime driving schedule, again undertaken in Canada, to ascertain if extended nighttime driving, while on a regular schedule, had adverse effects upon driver performance.

Concurrent with this study, the FHWA undertook, in early 1995, a survey of 500 drivers to assess current use, and to determine potential application of safe, legal, and effective fatigue-reducing and alertness-enhancing countermeasures.

The study was the most comprehensive "operational" study ever performed and benefitted from unprecedented international partnerships among governments, industry, and research communities. The study has already demonstrated that these partnerships are needed to develop solutions to the fatigue and alertness problem.

The FHWA anticipates that a final report of the "Driver Fatigue and Alertness Study" will be made available to the public this autumn. A copy of the final report will be placed in the public docket when it is completed.

At congressional direction, in 1991, 1992, and 1993, the FHWA has undertaken a series of additional studies associated with driver fatigue. These research efforts are:

1. Longer Combination Vehicle Driver Fatigue and Stress Study;
2. Driver Work and Rest Needs Study;
3. Interstate Rest Area Availability Study;
4. Obstructive Sleep Apnea Study;
5. Commercial Driver Fitness-for-Duty Testing Study; and
6. Performance of Older Commercial Drivers Study.

Longer Combination Vehicle Driver Fatigue and Stress Study

Section 4007 of the Intermodal Surface Transportation Efficiency Act (ISTEA), Pub. L. 102–240, 105 Stat. 1914, directed the Department to perform a study on the possible effect of multiple-trailer combination vehicle (MTCV) operations on driver stress and fatigue. Working together with the Battelle Human Affairs Research Center and the Oregon Trucking Association, the FHWA and the NHTSA directed this 24-driver, 2,700 mile study that used specially equipped and loaded single and triple-trailer combination vehicles under controlled experimental conditions. Typical operating conditions were encountered and standard operating practices were followed. Tractors were equipped with video and digital equipment to gather data on the drivers' performance during the study.

Test drivers answered standardized questionnaires concerning their perception of stress and fatigue during the driving day. In addition, measurements were taken of the drivers' physiological responses, mental processes associated with driving safety and performance, and driving performance. Of the nineteen measures used in the study, only two produced statistically significant results. These were a measure of perceived workload, and a measure of steering wheel reversals. Interestingly, only the drivers' *subjective perception* of increased workload while driving MTCV's suggested that such operations might result in increased driver stress and fatigue.

This study indicated that the most important contributing factor in predicting stress or fatigue is the driver. Tolerance of potentially fatiguing conditions varies a great deal among professional truck drivers. The study also has shown that, although the number of trailers attached to the tractor may influence a drivers' *subjective* estimate of his or her fatigue, the related *objective* measures of performance and physiological condition registered very little, if any, difference. It appears that vehicle variations alone are not significant predictors of driver fatigue and stress under *these* conditions (e.g., drivers, daytime driving, 12 consecutive hours off-duty).

Driver Work and Rest Needs Study

This study is designed to assess the work and rest needs of CMV drivers. Working with the Walter Reed Army Institute of Research, the FAA, and the National Institutes of Health (NIH), the FHWA seeks to determine driver performance and physiological and subjective states after varying amounts of sleep. This study is using four new and different technologies to develop a means by which alertness-related performance can be measured and driver proficiency predicted (i.e., performance-based technology). This study is projected to be completed in late 1997. The study will also attempt to determine how much off-duty time is required to ensure a driver obtains enough sleep to be sufficiently rejuvenated to safely operate a CMV.

Interstate Rest Area Availability Study

The TRI and its subcontractors studied the adequacy of truck parking at public rest areas on the Dwight D. Eisenhower Interstate Highway System and private truck stops adjacent to those highways. States were surveyed about parking capacity and restrictions at public rest areas. The research also observed truckers' usage of public and private stops along Interstate Route 81, interviewed CMV drivers, and surveyed motor carriers and private truck stop operators about the perceived need for, and availability of, Interstate CMV parking. Based partly upon this information, assessments of utilization and demand for public and private parking spaces for CMVs were also undertaken. A final report on the study's findings was completed in May 1996.

Obstructive Sleep Apnea Study

Working with the TRI and the University of Pennsylvania Hospital, the FHWA is responding to congressional direction to examine the problem of obstructive sleep apnea among CMV operators. The overall goals of the study are to:

1. Obtain a more precise estimate of obstructive sleep apnea based upon CMV operators' responses to a questionnaire regarding the prevalence of sleep apnea in a sample of CMV drivers who may be at high risk because of the disorder; and
2. Estimate the level of sleep apnea (i.e., identify a threshold of apneatic episodes during sleep) at which the CMV drivers may be operating while impaired.

First identified in the 1960's, obstructive sleep apnea has been recognized as a major health problem, affecting millions of Americans. The prevalence of obstructive sleep apnea among CMV drivers may be greater than the four percent estimated in the general male population. Truck driving is largely a sedentary occupation and, therefore, conducive to obesity. Obesity, along with age and high blood pressure, is associated with an increased risk of obstructive sleep apnea.

Because obstructive sleep apnea is a disorder characterized by breathing cessations, it interrupts restful sleep. The quality of sleep is greatly diminished due to frequent awakenings. Identified as a leading cause of excessive daytime sleepiness, obstructive sleep apnea has been found to greatly increase the potential for accidents among sufferers. Thus, it poses a potentially significant risk to drivers of CMVs and, in turn, the motoring public.

To obtain an accurate estimate of the prevalence of obstructive sleep apnea among the CMV driver population, the University of Pennsylvania Hospital first conducted a pilot test to validate a questionnaire using 200 truck drivers drawn from the TRI's list of operators. Results of that pilot test, obtained in January 1995, demonstrated the feasibility of such a sampling effort in obtaining information about apneatic conditions from the CMV driving population. During 1996, a full-scale sample will be undertaken, with results provided on the prevalence of obstructive sleep apnea among the CMV driving population.

Commercial Driver Fitness-for-Duty Testing Study

At congressional direction, the FHWA also has sought to identify and test technologies, both in-terminal and in-vehicle, that will detect and identify a driver who is not fit for duty. An initial study, begun by the TRI and its partner Systems Technology, Inc. (STI) in 1993, undertook an evaluation of the accuracy and reliability of four fitness-for-duty performance tests. The research evaluated the testing devices to determine their effectiveness at motor carriers' terminals, and also sought to determine if miniaturized versions of the equipment could be successfully used in-cab, to test drivers away from their home terminal.

Data were collected on drivers' test results, driver and motor carrier management acceptance of the tasks, the effects of terminal and in-cab environments on the hardware, and system reliability and maintainability. The conclusion of this initial study was that in-cab testing was feasible. The findings of the study also recommended that, for a motor carrier's program to work effectively, testing had to be made mandatory, and the motor carrier had to permit drivers failing the test to stop driving and take a rest without penalty.

In early 1995, the FHWA entered into a second phase of fitness-for-duty testing, also with the TRI and STI. More frequent monitoring of driver alertness was instituted. Using a second-generation version of in-vehicle testing equipment employed in the first generation's effort, the TRI and its subcontractor also added a lane tracking device to monitor the driver's fitness-for-duty. Under the proposed study design, a driver using this device must first establish a "baseline" of performance that documented his or her own ability to keep a vehicle in its lane. If a deviation from the baseline is detected, the driver would be alerted. If the deviation continues, both the driver and the motor carrier would be notified. The test driver then would be required to stop the vehicle at the nearest safe location and take a five minute test. Depending upon the test results, the driver would either be permitted to continue driving or be required to sleep, or nap, before continuing to drive.

The NHTSA is focusing on continuous monitoring of drivers in its research on commercial driver fitness-for-duty testing. The ultimate goal is to produce a practical vehicle-based driver alertness monitor for use in heavy vehicles. The technologies employed include systems to evaluate the driver's steering and lane tracking performance, and his or her psychophysiological condition (principally eye activity). A contemporary and complementary fitness-for-duty study to the FHWA's research, the Carnegie-Mellon Research Institute is conducting the NHTSA's research. This research will use several equipment prototypes mounted in two CMVs. This work is based upon previous driving simulator studies at the Virginia Polytechnical Institute and State University. It will produce a recommended specification for heavy vehicle driver alertness monitors, including both detection algorithms and appropriate driver warning devices.

Performance of Older Commercial Drivers Study

In 1993, the Congress directed the FHWA to undertake research to determine the influence of age on CMV drivers' performance. Again relying on the services of the TRI and subcontractors, the study investigated 15 human perceptual, cognitive, and psychomotor abilities. Age, by itself, was not found to be a significant predictor of driving performance. Nevertheless, older CMV drivers (defined in this study as 50 years or older) are more likely to demonstrate age-related perceptual, cognitive, and psychomotor impairments which directly influence driving performance. However, their performance was improved after they had taken training.

B. Future FHWA Research Envisioned

A number of new research projects are planned for 1996 and beyond that will evaluate driver performance and needs. A number of these will be undertaken in response to congressional recommendation and direction. Topics include:

a. Assessment of Technological Interventions;

b. Impact of Loading and Unloading Commercial Vehicles on Driver Fatigue and Alertness;

c. Drivers Engaged in Local/Short Haul Operations;

d. Sleeper Berth Use and Fatigue;

e. Shipper and Consignee Involvement in Driver HOS Violations;

f. Scheduling Practices;

g. Driver Proficiency and Wellness; and

h. Crash Investigation Project.

Assessment of Technological Interventions

In 1996, the FHWA, in cooperation with the TRI, will begin an assessment of the most promising technological interventions and other countermeasures identified in the Driver Fatigue and Alertness Study and other research. Individual interventions and countermeasures will be field-tested and evaluated in terms of their feasibility and cost-effectiveness. Also with the TRI, the FHWA will develop, evaluate, and disseminate educational and training programs targeted at CMV drivers, dispatchers, risk managers, and shippers. Current knowledge about fatigue and effective countermeasures, including ways CMV drivers can recognize impending drowsiness, will be explained.

Impact of Loading and Unloading Commercial Vehicles on Driver Fatigue and Alertness

In 1978, Human Factors Research, Incorporated (now Essex Corporation) conducted a study for the NHTSA which included a limited assessment of the influence of driver fatigue on cargo loading and unloading. Using a simulated loading task, the study sought to determine if cargo loading either enhanced or reduced the CMV driver's alertness. The results indicated mixed effects on the driver's subjective feelings, physiological status, and performance. It appeared to researchers that performing the loading task had "some beneficial activating effects that persisted for much of the driving stint, especially during late night/early morning trips." Yet, the final report also found "considerably greater incidence of 'critical incidents' involving sleepiness or lack of attention for drivers who engaged in moderate work."

The limited 1978 assessment left unresolved the issue of whether substantial periods of loading and unloading a CMV would introduce or exacerbate fatigue to such an extent that driving would be impacted. The FHWA has for many years desired to further assess the effects of this simulated loading task, in particular on long-distance, over-the-road operators engaged in interstate commerce. The FHWA has deferred action on this important effort in order to first complete the multi-year "Driver Fatigue and Alertness Study" and, thus, be able to employ driver assessment technologies validated in that study in the evaluation of the impact of loading and unloading. In 1996, in response to congressional direction, the FHWA is initiating a study of this frequent work requirement.

As currently proposed, the study will be undertaken in two phases. The first phase, carried out in cooperation with the TRI and the PFMI, will undertake a critical literature review which: (1) Concentrates on the effects of physical activity on alertness, fatigue, and performance; (2) identifies critical variables for field study; and (3) identifies appropriate measures and measurement technology. The FHWA believes it is important to understand, from the motor carrier industry perspective, what actual physical requirements are being imposed on drivers by representative types of cargo being transported. Once these activities are completed, a second phase of study will assess the actual physical demands imposed in performing loading and unloading tasks by examining an appropriate industry segment and its work schedule. This second phase will include the collection of on-the-road measurements of driver alertness, fatigue, and performance. The second phase will provide a report that analyzes the relationship between the loading/unloading requirement and fatigue.

Drivers Engaged in Local/Short-Haul Operations

The local/short-haul operations segment of the motor carrier industry engages in work practices which distinguish it from the long-haul, over-the-road interstate operation. Chiefly, these practices are characterized by pick-up and delivery activities which result in the vehicle operator engaging in non-driving activities (e.g., package pick-up and delivery) which consume a significant portion of the driver's work day. This type of CMV driving was originally intended to be included in the baseline "Driver Fatigue and Alertness Study" begun in 1989. It had to be postponed due to financial constraints and the need to focus resources on the significant data analysis activity required by the over-the-road portion of the study. In fiscal year 1996, in response to congressional direction, the FHWA plans to award a contract for a study focusing on driver fatigue in local/short-haul operations. The planned study will employ both direct observation (i.e., instrumented vehicle studies) and driver interviews and focus groups. These will help to determine the role played by fatigue and related factors in driver errors and incidents involving local/short-haul truck operations. In addition, the study will: (1) Analyze crash statistics involving driver fatigue and related factors as principal or contributing causes of local/short-haul commercial vehicle crashes; and (2) investigate a sample of crashes to obtain more in-depth crash causation data. The study will also compare local/short-haul to long-haul operations in terms of driver fatigue, associated safety concerns, and the overall safety picture.

Sleeper Berth Fatigue

In its limited 1978 study, Human Factors Research, Incorporated, assessed the impact of sleeper berth use. That study indicated that CMV drivers who rely upon sleeper berths for rest demonstrated performance effects of sleep degradation, such as lower scores on hand-eye coordination tests and a higher incidence of lane drifting and drowsiness. The FHWA intends to award a study, in 1996, that will assess the impact of sleeper berth use upon the level of driver alertness. The study would assess the quality of rest achieved while the vehicle is both stationary and in motion. Because sleeper berth users tend to operate on irregular schedules, the FHWA would like to include in the research an evaluation of the effects of irregular schedules and sleeper berth use.

Shipper and Consignee Involvement in Driver HOS Violations

The Senate Report to the 1996 Department of Transportation and Related Agencies Appropriations Act called upon the FHWA to "sign a contract before November 1, 1995, to conduct research to determine the scope, nature, and extent of shipper involvement in noncompliance with the safety regulations" (S. Rep. No. 126, 104th Cong., 1st Sess.97 (1995)). This year, the FHWA has undertaken both contractual and in-house tasks to satisfy this requirement. The FHWA has engaged Calspan Corporation to undertake a series of focus group sessions and in-depth interviews. This undertaking will generate qualitative data about the state of shipper (and consignee) demands on the motor carrier industry and its drivers. Concurrent with this effort, the FHWA will seek to identify and analyze existing data that may help define the scope of the problem, pinpoint factors that appear to be related to driver violations of the HOS regulations, and eliminate others which do not appear to be correlated. Subsequent tasks still remain to be determined, with their selection and design to be linked, in part, to initial findings. The FHWA may decide to test specific segments of the motor carrier industry where evidence indicates, for example, that time-sensitive deliveries are the norm and pressure from shippers and consignees may tend to be greater than the norm.

The FHWA envisions that this study will indicate some important safety issues, and is prepared to work with the Congress and various industry groups toward their resolution. Such resolution might involve a determination of effective enforcement and educational activities that would help to reduce any misunderstanding about the critical need for driver compliance with the HOS rules.

Scheduling Practices

Concurrent with the shipper study, the FHWA, in 1996, will also begin surveying a variety of CMV drivers, motor carriers, and shippers to determine the prevalence of various shipping and scheduling practices, associated driving schedules, and possible effects of fatigue. This work will be undertaken in cooperation with the TRI and the PFMI. A proposed outcome of this research would be a symposium of recognized experts in shift work, traffic management, trucking operations, and trucking safety, convened to review the survey findings and make appropriate recommendations for safer operations.

Driver Proficiency and Wellness

As the current decade draws to a close, the FHWA plans to expand its efforts on behalf of the CMV driver beyond the traditional areas of fatigue detection and prevention. The demand for fast, efficient passenger and cargo delivery is placing increasing pressures upon drivers. This is resulting not only in immediate performance decrement, but also long-term stress. Consequently, our efforts to counteract fatigue and stress must not only continue but be expanded to promote the creation of positive models of driver wellness and proficiency. At this stage, the FHWA believes that non-regulatory approaches being developed by the National Motor Carrier Advisory Committee's Subcommittee on Drivers, the PFMI, and the OOIDA, such as education, could be the key to the success of this effort. Such wellness education might address such lifestyle issues as nutrition, exercise, and, of course, sleep.

Crash Investigation Project

This project, planned to begin in 1996, will compile a database of in-depth crash investigation reports from the various States and other sources in order to determine the contributing factors, causes, fault, or reasons for truck and bus crashes. This CMV crash causation study is intended to employ a comprehensive classification of crash causes (including drowsiness/fatigue as well as other forms of driver inattention) and a broad, representative sample of CMV crashes. The FHWA regards these as critical methodological elements in any valid study of CMV crash causation.

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