Commercial Truck and Bus Safety

Synthesis 9

Literature Review on Health and Fatigue Issues Associated with Commercial Motor Vehicle Driver Hours of Work

A Synthesis of Safety Practice

Sponsored by the
Federal Motor Carrier
Safety Administration

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

COMMERCIAL TRUCK AND BUS SAFETY SYNTHESIS PROGRAM

Synthesis 9

Literature Review on Health and Fatigue Issues Associated with Commercial Motor Vehicle Driver Hours of Work

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Operations and Safety • Public Transit • Freight Transportation

Research Sponsored by the Federal Motor Carrier Safety Administration

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COMMERCIAL TRUCK AND BUS SAFETY SYNTHESIS PROGRAM

Safety is a principal focus of government agencies and private-sector organizations concerned with transportation. The Federal Motor Carrier Safety Administration (FMCSA) was established within the Department of Transportation on January 1, 2000, pursuant to the Motor Carrier Safety Improvement Act of 1999. Formerly a part of the Federal Highway Administration, the FMCSA's primary mission is to prevent commercial motor vehicle-related fatalities and injuries. Administration activities contribute to ensuring safety in motor carrier operations through strong enforcement of safety regulations, targeting high-risk carriers and commercial motor vehicle drivers; improving safety information systems and commercial motor vehicle technologies; strengthening commercial motor vehicle equipment and operating standards; and increasing safety awareness. To accomplish these activities, the Administration works with federal, state, and local enforcement agencies, the motor carrier industry, labor, safety interest groups, and others. In addition to safety, security-related issues are also receiving significant attention in light of the terrorist events of September 11, 2001.

Administrators, commercial truck and bus carriers, government regulators, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and underevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information available on nearly every subject of concern to commercial truck and bus safety. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the commercial truck and bus industry, the Commercial Truck and Bus Safety Synthesis Program (CTBSSP) was established by the FMCSA to undertake a series of studies to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern. Reports from this endeavor constitute the CTBSSP Synthesis series, which collects and assembles the various forms of information into single concise documents pertaining to specific commercial truck and bus safety problems or sets of closely related problems

The CTBSSP, administered by the Transportation Research Board, began in early 2002 in support of the FMCSA's safety research programs. The program initiates three to four synthesis studies annually that address concerns in the area of commercial truck and bus safety. A synthesis report is a document that summarizes existing practice in a specific technical area based typically on a literature search and a survey of relevant organizations (e.g., state DOTs, enforcement agencies, commercial truck and bus companies, or other organizations appropriate for the specific topic). The primary users of the syntheses are practitioners who work on issues or problems using diverse approaches in their individual settings. The program is modeled after the successful synthesis programs currently operated as part of the National Cooperative Highway Research Program (NCHRP) and the Transit Cooperative Research Program (TCRP).

This synthesis series reports on various practices, making recommendations where appropriate. Each document is a compendium of the best knowledge available on measures found to be successful in resolving specific problems. To develop these syntheses in a comprehensive manner and to ensure inclusion of significant knowledge, available information assembled from numerous sources, including a large number of relevant organizations, is analyzed.

For each topic, the project objectives are (1) to locate and assemble documented information (2) to learn what practice has been used for solving or alleviating problems; (3) to identify all ongoing research; (4) to learn what problems remain largely unsolved; and (5) to organize, evaluate, and document the useful information that is acquired. Each synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation.

The CTBSSP is governed by a Program Oversight Panel consisting of individuals knowledgeable in the area of commercial truck and bus safety from a number of perspectives—commercial truck and bus carriers, key industry trade associations, state regulatory agencies, safety organizations, academia, and related federal agencies. Major responsibilities of the panel are to (1) provide general oversight of the CTBSSP and its procedures, (2) annually select synthesis topics, (3) refine synthesis scopes, (4) select researchers to prepare each synthesis, (5) review products, and (6) make publication recommendations.

Each year, potential synthesis topics are solicited through a broad industry-wide process. Based on the topics received, the Program Oversight Panel selects new synthesis topics based on the level of funding provided by the FMCSA. In late 2002, the Program Oversight Panel selected two task-order contractor teams through a competitive process to conduct syntheses for Fiscal Years 2003 through 2005.

CTBSSP SYNTHESIS 9

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NOTICE

The project that is the subject of this report was a part of the Commercial Truck and Bus Safety Synthesis Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, or the Federal Motor Carrier Safety Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

To save time and money in disseminating the research findings, the report is essentially the original text as submitted by the research agency. This report has not been fully edited by TRB.

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FOREWORD

By Christopher W. Jenks
CTBSSP Manager
Transportation Research Board

This synthesis will be useful to commercial vehicle operators, federal and state agencies, and others interested in improving commercial vehicle safety. The report provides a review of literature relevant to health and fatigue issues associated with commercial vehicle driver hours of service. This literature review was specifically requested by the Federal Motor Carrier Safety Administration (FMCSA) to provide information related to their issuance of Hours of Service regulations in January 2004. Soon after the issuance of these regulations, a lawsuit was filed challenging the regulations. As a result of this lawsuit, a federal court ordered the new regulations to stay in effect while the FMCSA reviewed the regulations and presented its case in support of the regulations and/or prepared a new set of agreed upon Hours of Service regulations. To assist the FMCSA in conducting its review, the CTBSSP was asked to conduct a two-part literature review of relevant material. Part I contains a general literature review of the health and fatigue issues associated with commercial vehicle driver hours of service. For fatigue issues, the focus is on research that occurred after the Hours of Service regulations were published, as a literature review was performed to support these regulations. The literature review relating to health issues is more extensive, and covers studies conducted from 1975 to the present. Part II contains a literature review of references that were cited in response to a related FMCSA Notice of Proposed Rulemaking. In both Parts I and II, the literature reviews summarize the literature without drawing any conclusions as to how they specifically relate to the FMCSA Hours of Service regulations. Any conclusions in this area are left to the FMCSA and others.

Administrators, commercial truck and bus carriers, government regulators, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and underevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

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Part I

General Literature Review

LITERATURE REVIEW ON HEALTH AND FATIGUE ISSUES ASSOCIATED WITH COMMERCIAL MOTOR VEHICLE DRIVER HOURS OF SERVICE

SUMMARY

Since 1995, the U.S. Department of Transportation's Federal Motor Carrier Safety Administration (FMCSA) (formerly FHWA's Office of Motor Carriers) actively conducted a program of research, study, and industry outreach and education on commercial motor vehicle (CMV) driver alertness, fatigue, health, and wellness. There was much open public discussion, deliberation, and negotiation over the public rulemaking process from 1996 to 2003. In May 2003, FMCSA issued new hours of service (HOS) rules for CMV drivers with a planned implementation date of January 2004. After substantial amounts of training and preparation by government and the trucking industry, those new HOS rules went into effect January 4, 2004.

The January 2004 revised HOS rules extended allowable driving time to 11 hr and cut overall driver work to 14 hr before requiring a 10-hr break. The old HOS rules limited CMV driving to 10 hr, and allowed drivers to work 15 hr before taking a mandatory 8-hr break.

Public Citizen challenged those HOS rules in a lawsuit, alleging that the new HOS did not properly account for CMV driver health concerns. Responding to that lawsuit, in July 2004, the U.S. Court of Appeals for the Washington, D.C., Circuit ruled that DOT's FMCSA did not follow a congressional mandate to consider truck drivers' health in the revised HOS rules. FMCSA requested the federal court to stay its order and keep the current, revised HOS rules in effect until FMCSA can re-present its case or prepare a new set of HOS rules.

As one part of its efforts to reply to the Court of Appeals ruling on HOS, FMCSA requested the independent technical assistance from a third-party research team. FMCSA asked MaineWay Services to summarize the scientific and technical literature on CMV operator health, wellness, fatigue, and performance, as they relate to the hours a person works, or to the structure of the work schedule (e.g., on-duty/off-duty cycles, sleep time, etc.).

The MaineWay Services research team was assigned the task of literature review. This synthesis is designed to provide information to FMCSA on existing literature in this subject area.

OBJECTIVES AND SCOPE

This synthesis responds to the statement of work (see Appendix A): to review the scientific and technical literature in two topical areas related to HOS: (1) driver health and (2) driver fatigue.

Driver Health. The synthesis reviews and summarizes available information in the scientific and technical literature concerning HOS and CMV operator health. The purpose of the literature review was to provide information that clearly discusses in a scientific, experimental, quantitative, or qualitative way, the relationship between the hours a person works or the structure of the work schedule (e.g., on-duty/off-duty cycles, sleep time, etc.) and the impact on some medical conditions of concern to truck drivers. The literature review summarizes the characteristics and methodology of each study, so that each study's approach can be clearly understood and compared with other studies.

Driver Fatigue. The synthesis reviews and summarizes available information in the scientific and technical literature concerning HOS and CMV operator performance and fatigue, especially as they pertain to driver health. The purpose of this facet of the literature review is to provide information that clearly summarizes in a scientific, experimental, qualitative, and quantitative way the relationship between the hours a person works, drives, and the structure of the work schedule (on-duty/off-duty cycles, time on task, especially time in continuous driving, sleep time, etc.) and the impact of CMV driver fatigue and performance. The literature review summarizes the characteristics and methodology of each study, so that each study's approach can be clearly understood and compared with other studies.

SELECTION OF AND PARTICIPATION OF KEY PERSONNEL ON THE PROJECT

Following award of the contract for this research, Gene Bergoffen, Principal, MaineWay Services, appointed two technical panels, one on driver health and the other on driver fatigue. Mr. Bergoffen served as the project executive administrator and senior advisor, with the assistance of Gerald P. Krueger, PhD., as the senior technical advisor. After consultation with the FMCSA, Peter Orris, MD, MPH, was appointed as technical advisor and panel leader for the health literature review and Alison Smiley, PhD., was appointed as technical advisor and as the panel leader for the fatigue literature review. The background of the key project personnel is included in the following section.

Dr. Orris was assisted by Dr. Susan Buchanan. To provide additional peer input and advice in the health literature review, Dr. Orris elicited panel member participation from four additional experts listed in the Health Panel Members section. Ms. Smiley was assisted by Dianne Davis. To provide further input and advice in the fatigue literature review, Ms. Smiley elicited panel member participation from two additional experts listed in the Fatigue Panel Members section.

KEY PERSONNEL

Project Administration

Gene Bergoffen, MaineWay Services, Project Administrator and Senior Advisor

- Currently the Principal of MaineWay Services, a transportation research and consulting firm in Fryeburg, Maine

- Eight years as President and CEO, National Private Truck Council
- Co-investigator and co-author of *CTBSSP Synthesis 1*, "Effective Commercial Truck and Bus Safety Management Techniques"
- Leader of MaineWay Services Task Order Team for several CTBSSP Synthesis Projects; principal investigator of *CTBSSP Synthesis 8,* "Commercial Motor Vehicle Driver Safety Belt Usage"
- Broad experience in project management stemming from the organization of the Private Fleet Management Institute and including a number of research projects conducted when employed by Science Applications International Corporation

Gerald P. Krueger, PhD, Wexford Group International, Senior Technical Advisor
Highly experienced engineering psychologist and human factors specialist (36 years) and a Certified Professional Ergonomist (CPE)

- Recognized authority on sustained performance of aviators, heavy equipment operators, and of CMV driver fatigue, factors relating to driver wellness and health, and occupational and environmental medicine research
- Co-investigator on two truck driver simulator studies and one large field study on CMV truck driver alertness and fatigue issues
- Principal developer of two FMCSA and American Trucking Associations' (ATA) train-the-trainer courses: Mastering Alertness and Managing Commercial Driver Fatigue; and Gettin' in Gear Wellness, Health and Fitness for Commercial Drivers
- Co-investigator and co-author for *CTBSSP Synthesis 7,* "Motorcoach Industry Hours of Service and Fatigue Management Techniques."
- Co-investigator and principal ergonomist on *CTBSSP Synthesis 8*, "Commercial Motor Vehicle Driver Safety Belt Usage"

Health Panel

Peter Orris, MD, MPH

- Professor of Occupational and Environmental Health Sciences, University of Illinois School of Public Health, Cook County Hospital
- Director of Occupational Health Services Institute, Great Lakes Center for Occupational and Environmental Safety and Health, University of Illinois
- Chief of Service, Occupational and Environmental Medicine, University of Illinois at Chicago Hospital and Medical Center
- President, Medical Staff, Cook County Hospital
- Secretary/Treasurer, Journal of Public Health Policy
- Member of Medical Advisory Committee of International Brotherhood of Teamsters
- Author of multiple publications relating to public health topics and reviewer and participant in editorial boards of a range of professional journals related to public health topics

Susan Buchanan, MD, MPH

- Interim Program Director, Occupational Medicine Residency, University of Illinois at Chicago College of Medicine
- Author, several publications relating to Occupational Health
- Reviewer, *American Journal of Industrial Medicine,* 2004

Health Panel Members

- **Leslie Stayner, PhD.**
  - Professor and Director, Epidemiology and Biostatistics, University of Illinois, Chicago School of Public Health
  - Served as Chief of Risk Evaluation Branch, National Institute for Occupational Safety and Health, Education and Information Division, and in several other career positions relating to risk evaluation
  - Contributing Editor to *Journal of Industrial Medicine* and involved in a wide range of professional activities relating to industrial health
- **Eric Garshick, MD, MOH**
  - Assistant Professor of Medicine, VA Boston Healthcare System, Channing Laboratory, Brigham and Women's Hospital, Harvard Medical School
  - Served as Advisor, World Health Organization. International Program on Chemical Safety, Environmental Health Criteria for Diesel Fuel and Exhaust Emissions, Geneva, Switzerland
  - Served as consultant, U.S. EPA Science Advisory Board, Clean Air Scientific Advisory Committee Diesel Emissions Health Document
- **William Marras, PhD.**
  - Co-Director, Institute of Ergonomics, Ohio State University
  - Professor, Department of Physical Medicine, Biomedical Engineering Center, Ohio State University
  - Associate Editor, *Human Factors*
- **Natalie Hartenbaum, MD, MPH**
  - President and Chief Medical Officer of OccuMedix, Inc.
  - Adjunct Assistant Professor of Emergency Medicine/Occupational Medicine at the University of Pennsylvania
  - Editor-in-Chief of *CDME* (Commercial Driver Medical Examiner) *Review*

Fatigue Panel

Alison Smiley, PhD.

- President of Human Factors North, Inc., a Toronto-based human factors and engineering consulting company; and a Canadian Certified Professional Ergonomist (CCPE)
- 30 years experience in measurement of human performance, and human factors consulting, specializing in driver behavior, transportation safety, and shift work
- Senior specialist in assessment of work-rest schedules, shift work, hours of work and worker rest for transportation industries (railways, coast guard and marine vessels, trucking, etc.) and for nuclear power plant and manufacturing operations
- Project manager for several Transport Canada projects involving literature review and development of experimental protocols related to fatigue and minimum recovery periods for CMV drivers
- Forensic consultant with expertise on car and truck driver fatigue and shift-scheduling issues
- Consultant to both Canadian and U.S. governing bodies on trucking industry HOS regulations

Dianne Davis, M.Eng

- Associate Consultant, Human Factors North, Inc.
- More than 10 years experience conducting human factors analyses in a variety of different domains such as the safety of driver examination tests, the study of fatigue and truck driving, way-finding, and the design of medical mobile devices and online shipping tools

Fatigue Panel Members

- **Mark Rosekind, PhD.**
  - President and Chief Scientist, Alertness Solutions, Cupertino, California
  - Served as Research Scientist and Team Leader, Fatigue Countermeasures Program, Aviation Safety Research Branch, Flight Management and Human Factors Division, NASA Ames Research Center
- **Richard Hanowski, PhD.**
  - Leader, Truck and Bus Safety Group, Virginia Tech Transportation Institute
  - Experience includes transportation human factors with both heavy and light vehicles, laboratory and field testing, real-time automobile and heavy vehicle simulation, advanced system development and testing, design guideline development, and human performance evaluation

ORGANIZATION AND PRESENTATION OF PART I: GENERAL LITERATURE REVIEW

The literature review is presented in two sections: Health and Fatigue.
The health literature review has the following subsections:

- Executive summary,
- Process and methodology,
- Selection criteria,
- Review of primary sources,
- Article summaries,
- Summary of findings of literature, and
- Bibliography of primary and secondary sources.

The fatigue literature review has the following subsections:

- Process and methodology,
- Selection criteria,
- Article summaries,
- Summary of findings of literature,
- Research limitations,
- Complete primary sources and abstracts, and
- Secondary sources.

Appendix A of the synthesis presents the initial FMCSA prescribed statement of work. As called for in this statement, the team consulted with FMCSA on the ultimate make-up of the two literature review panels and on all other elements of the synthesis. Two briefings of the FMCSA staff were conducted during the course of the study to gain feedback on methodology, scope, and initial findings.

LITERATURE REVIEW—HEALTH

EXECUTIVE SUMMARY

The purpose of this literature review is to provide information that clearly discusses in a scientific, experimental, qualitative, and quantitative way the relationship between the hours a person works, drives, and the structure of the work schedule (on-duty/off-duty cycles, time on task, especially time in continuous driving, sleep time, etc.) and the impact on the health of truck drivers.

The PubMed access service was used for the literature search. PubMed was developed by the National Center for Biotechnology Information (NCBI) at the National Library of Medicine (NLM), located at the National Institutes of Health (NIH). The database contains bibliographic citations and author abstracts from more than 4,800 biomedical journals published in the United States and 70 other countries and is available via the NCBI Entrez retrieval system.

The initial search resulted in more than 1,850 articles. After screening and comparison with the questions to be answered in this exercise, 55 articles were reviewed. Twenty-five articles were chosen and summarized by a primary reviewer to be included in the synthesis based on the validity of the methodology, the relevance of the studied population to truck driving, and the quality of the statistical analysis of health outcomes. This review excluded those end points of fatigue, accidents, and road safety. The team evaluated the available information concerning driver health, with emphasis on chronic conditions, potentially associated with the 2003 HOS Regulations under consideration by the FMCSA.

Findings from the Literature

The following findings were drawn from the available literature reviewed as part of this synthesis.

- Lung cancer is likely caused by exposure to diesel exhaust and the longer that exposure lasts the more likely it is that a cancer will develop. Though the evidence linking this exposure to bladder cancer is less robust than that to lung cancer, it remains likely that there is such a relationship and that it is governed by a positive dose-response curve.
- There is some evidence that cardiovascular disease is caused in part by truck driving and its risk increases with the duration of this activity and the disruption of the sleep cycle.
- Based on exposure assessments, noise-induced hearing loss could well be a result of a working lifetime as a driver. This effect would be mitigated by the improvement in cab design reported to be occurring with consequent reduction in the intensity of noise reaching the driver.
- The evidence concerning a relationship between whole-body vibration (WBV) and musculoskeletal effects, such as low back pain (LBP) syndrome, relies primarily on self-reporting and application of risks derived from other environments. There are several studies available though that contain objective evidence of vertebral pathology related to an occupation as a professional driver. In conclusion, the available data support the hypothesis that there is likely a causative relationship between professional driving and a variety of vertebral disorders as well as LBP syndrome. While the literature suggests a role for WBV in the genesis of these disorders, it cannot be established based on current published materials.
- The literature related to commercial driving and other musculoskeletal disorders has the same limitations as the previous item, and while a causative relationship is logical, it can only be viewed as suggestive within this context.
- Gastrointestinal (GI) disorders would be expected to be impacted by varying shift assignments and disruption to normal circadian rhythm. While the information currently available documents an increase in symptoms in drivers, it is inadequate to implicate the specific risk factors that impact on these symptoms.
- The literature suggests, but does not establish, that disruption of circadian rhythm may have negative impacts on the general health of workers. The stabilization of shift especially when stabilized to a day schedule appears to have a beneficial effect on subjective health complaints though stabilizing to an evening or night schedule may not provide the same benefit.
- Finally, the literature contains no definitive information concerning (a) the relationship between reproductive health and duration of driving, (b) the effects of prolonged work hours, or (c) increasing driving from 10 to 11 hr while decreasing overall work time from 15 to 14 hr on the general health of workers. No data are available concerning the effects of allowing for increased sleep time from 6 to 8 hr in an adult working population.

PROCESS AND METHODOLOGY

Literature Search Source and Terms

The PubMed access service was used for the literature search. PubMed was designed to provide access to citations from biomedical literature, including bibliographic information that includes MEDLINE. MEDLINE is the NLM's premier bibliographic database covering the fields of medicine, nursing, dentistry, veterinary medicine, the health care system, and the preclinical sciences. MEDLINE contains bibliographic citations and author abstracts from more than 4,800 biomedical journals published in the United States and 70 other countries. The database contains more than 12 million citations dating back to the mid-1960s. Coverage is worldwide, but most records are from English-language sources or have English abstracts.

A search for articles after 1975 was performed on the database using the following terms:

Health effects and the following

- Commercial vehicle operator
- Commercial driver
- Driver occupation
- Vibration and motor vehicle

Based on the results from these searches, each of the search terms—motor vehicle operator, truck driver, occupation—was entered with the following:

- Bladder cancer
- Lung cancer
- Cardiovascular disease
- Myocardial infarction
- Spermatogenesis
- Low back pain
- Musculoskeletal disorder
- Kidney
- Renal cancer
- Hypertension

Each of the search terms—work hours, shift work, sleep schedule—was entered with the following:

- Gastrointestinal
- Diabetes
- Glycemic control
- Lipid
- Cholesterol
- Obesity
- Mental health
- Depression
- Peripheral neuropathy
- Neurologic disorder
- Reproductive
- Fertility
- Spontaneous abortion
- Musculoskeletal disorders

In addition, the following was searched:

- Swing shift work and health
- Rotating shift and health
- Sleep cycle and health

SELECTION CRITERIA

Primary Sources

The initial search resulted in more than 1,850 articles. When deemed appropriate by title, the abstracts were reviewed for relevance to the topics of CMV operator health and the health effects of work hours, shift work, and sleep schedule. The preliminary list included 139 abstracts. Those not pertaining to duration of work shift, duration of driving, working periods that shift over a 24-hr day, duration of sleep more than 6 hr, and effects of cumulative driving, were then removed from the list.

This left approximately 70 articles. Fifteen were not available either because they were published in foreign languages without translation or they were not found in the periodical section of the University of Illinois at Chicago's Health Sciences Library. They were not judged to provide unique information for the analysis, were not translated, and no further efforts were made to obtain them.

The remaining 55 articles were reviewed. Twenty-five were chosen and summarized by a primary reviewer to be included in the synthesis based on the validity of the methodology, the relevance of the studied population to truck driving and the quality of the statistical analysis of health outcomes.

These were abstracted and evaluated according to the form provided by FMCSA to highlight the relevance to this review. The assessments of these articles and of the conclusions as to their meaning for the report are the product of the primary reviewers.

The summaries focused specifically on the effects of extending driving time from 10 to 11 hr per day and extending the total hours worked per week provided for in the new regulations. They focused as well on the effects of disrupting circadian rhythm through swing swifts and of sleeping not more than 6 hr—conditions potentially relieved by the new regulations. The health effects of exposure to carcinogens and noise are cumulative so articles pertaining to long-term exposure, not just hours per day or week, were included in the cancer and hearing loss summaries.

Secondary Sources

Articles pertaining to causality alone, for example, the link between diesel exhaust and lung cancer, are included in the secondary references because these new regulations do not change this factor.

The National Institute for Occupational Safety and Health (NIOSH) document of April 2004, *Overtime and Extended Work Shifts: Recent Findings on Illnesses, Injuries, and Health Behaviors,* is not included in this review. This document reviewed the literature and was consistent with this review but did not add any new insight to the articles already gathered on those issues.

REVIEW OF PRIMARY SOURCES

The summaries are divided into the following subsections cardiovascular disease, lung cancer, bladder cancer, WBV effects, musculoskeletal disorders, GI disorders, noise-induced hearing loss, reproductive effects, effects of long work hours, effects of disruption of circadian rhythm, and effects of length of sleep.

Cardiovascular Disease

Two articles addressed the issue of hours of work and duration of exposure. A case-control study of the risk of myocardial infarction (MI) from exposure to motor exhaust found a positive association, although results were not significant (Gustavsson Mar 2001). A case-control study of the risk of MI from long working hours found a U-shaped relationship with mean working hours of ≥11 hr compared with working 9 to 11 hr with a trend toward increasing risk with increasing hours (Sokejima 1998).

Numerous articles were found on the association of cardiovascular disease and professional driving. These are included in the secondary references.

Lung Cancer

There are numerous articles reporting on an association between lung cancer and work in occupations where there is exposure to diesel exhaust and other combustion particles. Diesel exhaust is considered to be a probable lung carcinogen by the U.S. EPA, the World Health Organization, and U.S. Department of Health and Human Services National Toxicology Program. In this review, four articles addressed the issue of hours of work and duration of exposure.

A large case-control study in Germany found a significant association between lung cancer and employment as a professional driver, as well as evidence of a dose-response relationship by years of exposure to diesel exhaust (Bruske-Hohlfeld 1999). An exposure-response analysis and risk assessment of lung cancer and diesel exhaust found a significant increase in lung cancer risk with increasing estimated cumulative exposure to diesel exhaust among workers in the trucking industry based on an historical extrapolation of elemental carbon levels (Steenland Sept 1998). In a large case-control study of bus and tramway drivers in Copenhagen, a **negative** association between lung cancer and increased years of employment was found (Soll-Johanning 2003). Finally, a meta-analysis of 29 studies addressing occupational exposure to diesel exhaust and lung cancer showed that 21 of the 23 studies meeting the inclusion criteria observed relative risk estimates greater than one. A positive duration response was noted in all studies quantifying exposure (Bhatia 1998).

Several additional articles showing an association between exposure to diesel exhaust and lung cancer were found and listed in the secondary references. Three articles on lung cancer referenced in the notice of proposed rulemaking draft of December 17, 2004, as sent to Office of Management and Budget, are not included here because they did not address HOS or cumulative exposure; they were surveillance/prevalence studies.

Bladder Cancer

Several articles indicating an association between truck driving and bladder cancer were found. The most recent article was selected for summary. The others can be found in the secondary references.

Three articles addressed the association between duration of exposure to diesel exhaust and bladder cancer. A population based case-control study in New Hampshire found a positive association between bladder cancer and tractor-trailer driving as well as a positive trend with duration of employment (Colt 2004). A large retrospective cohort in Finland found increased standard incidence ratios for 6 types of cancer in truck drivers. Cumulative exposure to diesel exhaust was negatively associated with all cancers except ovarian cancer in women with high cumulative exposure (Guo 2004). A meta-analysis of 29 studies on bladder cancer and truck driving found an overall significant association between high exposure to diesel exhaust and bladder cancer as well as a dose-response trend. The authors concluded that diesel exhaust exposure may result in bladder cancer, but the effects of misclassification, publication bias, and confounding could not be fully taken into account (Boffetta Jan. 2001).

WBV Effects

As to objective findings of vertebral pathology, Heliovaara reported in 1987 on a case-control study of patients followed for 11 years after completing a normal physical exam. Those discharged from a hospital with the diagnosis of herniated lumbar intervertebral disc or sciatica were compared with 4 controls each. In men, the risk of being hospitalized due to herniated lumbar disc or sciatica was lowest in professional and related occupations, significantly higher in all other groups, and highest in blue-collar workers in industry and motor vehicle drivers. The variation in the risk between occupational groups of women proved less but was nevertheless still apparent. In contrast, a Finnish case-controlled study of monozygotic twins published in 2002 did not find any significant differences in vertebral degeneration between drivers and nondrivers over thousands of hours of estimated driving time (Battie 2002).

A study of Danish professional drivers in 1996 found that almost all men in occupations involving professional driving had statistically significant elevated risks of being hospitalized with prolapsed cervical intervertebral disc (Jensen 1996). This information was secured by following all economically active men in Denmark, identified on January 1, 1981, and followed for first hospitalization with prolapsed cervical intervertebral disc until December 31, 1990.

Finally, based on these and other studies, a review done for the British Columbia Workers' Compensation Board in 1999 concluded that "The data support a causal link between back disorders and both driving occupations and whole body vibration" (Teschke 1999).

Musculoskeletal Disorders

Studies addressing musculoskeletal disorders in truck drivers by and large evaluate the effects of WBV and are included in that section. A questionnaire survey of Japanese truck drivers found short resting time and irregular duty time to be significant risk factors for LBP. It also found positive but insignificant associations with long driving time in a day and in a week but the hours were not quantified (Miyamoto 2000). A study of knee pain in taxi drivers found a significantly increased risk of knee pain in workers with >10 hr of daily driving. A significant dose-response trend was also seen (Chen April 2004).

GI Disorders

A questionnaire study of auto workers in the Midwest found that schedule variability, evening shift, and number of hours worked per week were significantly associated with adverse GI outcomes (Caruso Dec. 2004).

Noise-Induced Hearing Loss

The American College of Occupational and Environmental Medicine in its 2002 statement on noise-induced hearing loss noted the following:

> . . . the risk of noise-induced hearing loss is considered to increase significantly with chronic exposures above 85 dBA for an 8-hr time-weighted average (TWA). In general, continuous noise exposure over the years is more damaging than interrupted exposure to noise which permits the ear to have a rest period.

The Occupational Safety and Health Administration (OSHA) noise exposure standard for the workplace for unprotected ears is 90 dBA limited to 8 hr per day. FMCSA has adopted a 90 dBA noise standard.

In 1995, the Office of Motor Carriers conducted a study of noise in CMVs (Robinson et al. 1997). The results of this study showed that noise levels in CMV cabs as reported over the last 25 years (1970 to 1995) have decreased. Other environmental studies confirm that overall cab noise levels have declined over this period as documented by several studies and reported in Robinson (1997).

This study found that the overall broadband sound pressure level for the nine trucks evaluated was 89.1 dBA for eight conditions of highway driving. The truck-cab average of 89.1 dBA was very close to the FMCSA permissible exposure limit of 90 dBA based on the OSHA 8-hr day TWA standard. This study measured the noise exposure of 10 truck drivers during normal commercial runs of 8 to 18 hr. The noise was measured with rest breaks, meal breaks, and refueling breaks included, so they represented realistic projections of actual driver exposure.

In a more recent study of a variety of models, makes, and age of tractors as well as routes that covered different types of Canadian terrain, noise exposure was measured (more than 400 measurements) under several conditions. The noise level recorded ranged from 78 to 89 dBA, with a mean of 82.7 dBA. Trucks with cabs mounted over the engine were quieter than other trucks by about 2.6 dBA. When the radio was on and the side window open the levels were regularly 85 dBA and in 10% of the cases above 90 dBA (Seshagiri 1998).

Reproductive Effects

Two studies were reviewed that addressed years of driving and male reproductive function. Because this exposure duration does not relate to daily or weekly driving hours, these articles are secondary references.

Effects of Long Work Hours

In a study on employees from 45 companies in the Netherlands, need for recovery scores (subjective measure of the self-perceived need to rest) were significantly elevated in those working 9 to 10 hr per day, >40 hr per week with frequent overtime (Jansen 2003). A literature review of recent empirical research on extended work hours and health confirms findings from studies on cardiovascular diseases, illnesses leading to disability retirement, and subjectively reported ill health (van der Hulst 2003).

A review document published by NIOSH in April 2004 titled "Overtime and Extended Work Shifts: Recent Findings on Illnesses, Injuries, and Health Behaviors" (Publication No. 2004-143), documents the lack of data on general health effects and even when looking at fatigue and accidents identifying "differences between 8-hr and 12-hr shifts are difficult because of the inconsistencies in the types of work schedules examined across studies. Work schedules differed by the time of day (i.e., day, evening, night), fixed versus rotating schedules, speed of rotation, direction of rotation, number of hours worked per week, number of consecutive days worked, number of rest days, and number of weekends off."

Effects of Disruption of Circadian Rhythm

Two studies using experimental conditions to evaluate the effect of circadian rhythm disruption on insulin secretion found increased insulin resistance and glucose response associated with a longer sleep-wake cycle such as that which might be found with rotating shift work (Morgan 1998).

Two-hundred sixty-one shift workers completed the standard shift work index in an investigation of health and well-being (Barton 1994). Workers on an advancing system were more likely to complain of digestive and cardiovascular (CV) disorders then those on a delayed rotating system. Authors concluded that the combination of direction of rotation and length of break when changing from one shift to another may be a critical factor in the health and well-being of shift workers.

In a thorough review of the literature on shift work and health up to 1999 appearing as a chapter in a hardbound text (Scott 2000), the author concludes that GI, cardiovascular disease, and reproductive dysfunctions are more common in shift workers and that these effects may be due to shift work factors such as rotating or fixed shifts, number of nights worked consecutively, predictability of schedule, and length of shift and starting time. Exacerbation of medical conditions such as diabetes, epilepsy, psychiatric disorders as well as the diseases noted above may occur due to sleep deprivation and circadian rhythm disruption.

Effects of Length of Sleep

No articles were found that demonstrated a clear health impact of increasing sleep time during the work week from 6 hr (reflecting the sleep time that could occur with 8 hr off work allowing for travel time) to 8 hr (reflecting the sleep time that could occur under the new regulations with 10 hr off work).

ARTICLE SUMMARIES*

Reviewer: Susan Buchanan

Title: Bruske-Hohlfeld, I., Mohner, M., Ahrens, W., Pohlabeln, H., Heinrich, J., Kreuzer, M., Jockel, K.H., and Wichmann, H.E. "Lung cancer risk in male workers occupationally exposed to diesel motor emissions in Germany." Am J Ind Med. 1999 Oct;36(4):405–14.

Abstract: Background: Although in several epidemiological studies exposure to diesel motor emissions (DME) shows an elevated lung cancer risk, it is still controversial whether DME is a human carcinogen. Methods: In a pooled analysis of two case-control studies on lung cancer in Germany a total of 3,498 male cases with histologically or cytologically ascertained lung cancer and 3,541 male population controls were included. Information about lifelong occupational and smoking history was obtained by questionnaire. Drivers of lorries, buses, taxies, diesel locomotives and forklift trucks, bulldozers, graders, excavators, and tractors, were considered as exposed to DME and their cumulative exposure was estimated. All odds ratios were adjusted for smoking and asbestos exposure. Results: The evaluation of lung cancer risk for all jobs with DME-exposure combined showed an odds ratio of OR = 1.43 (95%-CI: 1.23–1.67). Most pronounced was the increase in lung cancer risk in heavy equipment operators (OR = 2.31 95%-CI: 1.44–3.70). The risk of tractor drivers increased with length of employment and reached statistical significance for exposures longer than 30 years (OR = 6.81, 95%-CI: 1.17–39.51). The group of professional drivers (e.g., trucks, buses, and taxies), showed an increased risk only in West Germany (OR = 1.44, 95%-CI: 1. 18–1.76), but not in East Germany (OR = 0.83, 95%-CI: 0.60–1.14). DME-exposure in other traffic-related jobs (e.g., diesel engine locomotive drivers, switchmen, forklift operators) was associated with an odds ratio of OR = 1.53 (95%-CI: 1.04–2.24). Conclusions: The study provides further evidence that occupational exposure to diesel motor emissions is associated with an increased lung cancer risk.

Methodology: Two case-control studies were pooled for a joint analysis: all patients born in Germany after 1913 and diagnosed with lung cancer between 1988 and 1993 were used in one of the studies. The other study evaluated residents in 4 regions of Germany who were diagnosed with lung cancer in 1994. Controls for both studies were selected at random from municipal registries. A standardized questionnaire was performed in face-to-face interviews to obtain demographic information and job histories. Exposure to diesel motor exhaust was characterized by years of exposure after evaluating job task descriptions. Lung cancer risk was calculated according to the cumulated exposure and with respect to job group.

Scope of Work: To estimate lung cancer risk in workers occupationally exposed to diesel motor exhaust.

Sample Size: 3,498 cases and 3,541 controls

Industry Sector: Professional drivers

Major Limitations: Exposure was estimated based on participants' self-reported job task history.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Odds ratios were adjusted for smoking and asbestos exposure and showed that professional drivers had significantly higher rates of lung cancer. Workers of any category who were exposed to diesel motor exhaust for between 20 and 30 years had significantly higher rates of lung cancer. Risk increased with increased duration of exposure. And compared with workers who had never been exposed, those who were exposed had a 43% higher rate of lung cancer.

*Summaries are presented in the order submitted by the researchers.

"Our study results show an increasing lung cancer risk for professional drivers, adjusted for smoking and asbestos exposure (Table III), which is similar to the results of most other epidemiological studies." (p. 412)

Reviewer's Notes: Though retrospective with estimated exposures, this study, with a large sample population, showed significant associations between lung cancer and both exposure to diesel exhaust and a dose-response.

Reviewer: Susan Buchanan

Title: Colt, J.S., Baris, D., Stewart, P., Schned, A.R., Heaney, J.A., Mott, L.A., Silverman, D., and Karagas, M. "Occupation and bladder cancer risk in a population-based case-control study in New Hampshire." Cancer Causes Control. 2004 Oct;15(8):759–69.

Abstract: Objective: To identify occupations with excess bladder cancer risk in New Hampshire, where bladder cancer mortality rates have been elevated for decades. Methods: Lifetime occupational histories were obtained from interviews with 424 cases and 645 controls in a population-based case-control study. Unconditional logistic regression models were used to estimate odds ratios (OR) and 95% confidence intervals (CI) for each occupation, adjusted for age and smoking. Analyses by duration of employment were carried out and interactions with smoking were examined. Results: Male tractor-trailer truck drivers had an elevated risk for bladder cancer (OR = 2.4, CI = 1.4–4.1), with a significant positive trend in risk with increasing duration of employment (P (trend) = 0.0003). Male metal/plastic processing machine operators also had a significant excess (OR = 4.9, CI = 1.6–15.1), attributable mainly to molding/casting machine operators (OR = 16.6, CI = 2.1–131). Elevated risk was also observed for male fabricators, assemblers, and hand workers (OR = 1.8, CI = 1.0–3.4). Women in certain sales occupations (sales clerks, counter clerks, and cashiers) had a significant excess risk (OR = 2.2, CI = 1.3–3.9) and a significant trend with duration of employment (P (trend) = 0.016), as did female health service workers (OR = 4.1, CI = 1.6–10.7; P (trend) = 0.014). There was a positive interaction between smoking and employment as a health service worker (p = 0.036). Conclusions: These findings are generally consistent with previous studies. Elevated risks for male molding/casting machine operators, female sales workers, and female health service workers, especially those with a history of smoking, require further investigation.

Methodology: This study is part of a larger population-based case-control study evaluating risk factors for bladder cancer in New Hampshire. This paper reports on the occupational data. New Hampshire residents diagnosed with bladder cancer between July 1994 and June 1998 were identified from the state cancer registry. Controls were selected from the Department of Transportation population lists and matched for age and gender. Participants underwent a detailed in-home interview and information on job history was collected. Odds ratios were calculated adjusting for age and smoking status.

Scope of Work: To identify high-risk occupations in New Hampshire, where bladder cancer mortality rates have been elevated for decades, and to re-examine occupations that have been found to be associated with bladder cancer in previous studies.

Sample Size: 424 cases, 645 controls

Industry Sector: Tractor-trailer truck drivers

Major Limitations: This study excludes cases which did not survive to the time of the interview, such as those with rapidly growing or late diagnosed cancers (e.g., most severe cases). This would be a positive bias if another factor produced a more aggressive picture than driving exposure and a negative bias if the reverse was true. Exposure duration had only 2 categories: employed as truck driver <5 years or ≥5 years.

Findings Directly Related to HOS (include page references):

Driver Health (General)

Tractor-trailer truck drivers had an excess bladder cancer odds ratio of 2.3, which was significant. See Table 2. There was a positive trend of increasing risk with duration of employment. See Table 3. Duration of employment was categorized by <5 year or ≥5 years. "In our study, bladder cancer risk was higher among men who drove trucks typically fueled by diesel (tractor-trailers) than among drivers of other types of trucks, and there was no increase for taxicab or bus drivers. Thus, our study supports the possibility of diesel exposure as the putative factor." (p. 765)

Reviewer's Notes: This study was chosen from several that have shown significant odds ratios for bladder cancer in truck drivers (see secondary references). Although the characterization of exposure was limited, it was the most recent study published on this issue. It showed both a positive association between truck driving and bladder cancer and a dose-response trend between drivers exposed ≥5 years compared with those with exposure for <5 years.

Primary Reviewer: Susan Buchanan

Complete Title: Guo, J., Kauppinen, T., Kyyronen, P., Heikkila, P., Lindbohm, M.L., and Pukkala, E. "Risk of esophageal, ovarian, testicular, kidney and bladder cancers and leukemia among Finnish workers exposed to diesel or gasoline engine exhaust." Int J Cancer. 2004 Aug 20;111(2):286–92.

Abstract: Occupational exposure to diesel exhaust has been classified as probably carcinogenic and occupational exposure to gasoline engine exhaust as possibly carcinogenic to humans. Earlier results concerning cancers other than lung cancer are scarce and inconsistent, and exposure-response relations have seldom been reported. We followed up a cohort of all economically active Finns born between 1906 and 1945 for 30 million person-years during 1971–1995. Incident cases of esophageal cancer (n = 2,198), ovarian cancer (5,082), testicular cancer (387), kidney cancer (7,366), bladder cancer (8,110) and leukemia (4,562) were identified through a record linkage with the Finnish Cancer Registry. Occupations from the population census in 1970 were converted to exposures to diesel and gasoline engine exhausts with a job-exposure matrix (FINJEM). Cumulative exposure (CE) was calculated as product of prevalence, level and estimated duration of exposure. The relative risk of cancer for exposure categories in relation to the unexposed group was calculated using the Poisson regression model and adjusted for confounders. An increasing relative risk for ovarian cancer was observed with the increasing CE of diesel exhaust (p for trend = 0.006). The relative risk in the highest CE category was 3.69 (95% CI = 1.38–9.86). For gasoline engine exhaust, the relative risk was significantly increased only in the middle CE category (1.70; 95% CI = 1.11–2.62). Slight elevations of relative risk for bladder and kidney cancers were found at the lowest exposure level of engine exhausts, largely attributable to drivers. No effect of the exposures was observed for the other cancers. This study suggests an exposure-response relation between diesel exhaust and ovarian cancer. Copyright 2004 Wiley-Liss, Inc.

Methodology: The study cohort comprised all economically active Finns born between 1906 and 1945. The incident cases of esophageal cancer, ovarian cancer, testicular cancer, kidney cancer, bladder cancer, and leukemia, diagnosed between 1971 and 1995 among persons born between 1906 and 1945 were extracted from the Finnish Cancer Registry. A job-exposure matrix was created on the basis of the census occupation and a national job-exposure matrix (FINJEM). The exposure estimates were based on exposure measurements, hazard surveys, and the judgments of 20 Finnish occupational hygienists. Since the exposure to diesel exhaust decreased in most occupations between 1945 and 1984, cumulative exposure was estimated for 5-year birth cohorts. Cumulative exposure to diesel exhaust was categorized into three categories: lowest, middle, and highest, in mg/m^3-years. Risk ratios were controlled for cancer-specific confounding factors: socioeconomic status, cigarette smoking, alcohol consumption, body mass index (BMI), number of children (for women), and occupational exposure to ionizing radiation and aromatic hydrocarbon solvents.

Scope of Work: To assess the risk of leukemia and cancers of the esophagus, ovary, testis, kidney and bladder suspected to be associated with engine exhausts.

Sample Size: 2,198 cases of esophageal cancer, 5,082 cases of ovarian cancer, 387 cases of testicular cancer, 7,366 cases of kidney cancer, 8,110 cases of bladder cancer, and 4,562 cases of leukemia

Industry Sector: Truck drivers; no further characterization

Major Limitations: Exposure data not specific to individual cases

Findings Directly Related to HOS (include page references):

Driver Health (General)

Standard incidence ratios of all six types of cancer in truck drivers were all greater than 1.0 and leukemia was statistically significant (Table II). Relative risks for cancers in occupations exposed to high, middle, or low levels of engine exhaust were significant for high cumulative exposure to diesel exhaust and ovarian cancer (Table III). Relative risks for high or middle cumulative exposures were all insignificant for esophageal cancer, testicular cancer and leukemia. Kidney and bladder cancer were associated with low exposures. "Applying more sophisticated analysis to the same data, the present study revealed a positive exposure-response relation between ovarian cancer and diesel exhaust." (p. 290) "In the present study, we did not observe any positive exposure-response relations between engine exhausts and the other 5 cancers." (p. 290)

Reviewer's Notes: This study addresses general causality as well as dose-response. Relative risks for all six types of cancer were greater than 1. Regarding dose-response, this was a negative study except for the interesting association between ovarian cancer and high cumulative exposure to diesel exhaust.

Reviewer: Susan Buchanan

CompleteTitle: Jansen, N., Kant, I., van Amelsvoort, L., Nijhuis, F., and van den Brandt, P. “Need for recovery from work: evaluating short-term effects of working hours, patterns and schedules.” Ergonomics. 2003 Jun 10;46(7):664–80.

Abstract: In this paper working hours, patterns, and work schedules of employees were evaluated in terms of need for recovery from work. Self-administered questionnaire data from employees of the Maastricht Cohort Study on Fatigue at Work (n = 12,095) were used. Poisson regression analyses and multivariate logistic regression analyses revealed that higher working hours a day and working hours a week generally went together with more need for recovery from work. Overtime work was associated with higher need for recovery from work in both genders. Both male and female three-shift or irregular shift workers had higher odds of elevated need for recovery compared with day workers. When additionally controlling for work-related factors, need for recovery levels among shift workers substantially lowered. This study clearly showed that working hours and schedules are associated with need for recovery from work, with different associations for men and women. The associations between work schedules and need for recovery from work were very interrelated with other work-related factors. Future studies could further investigate the possibility that (a) shift work might function as a proxy of other work-related factors that explain the different levels in need for recovery from work or (b) job demands are perceived higher among shift workers and may therefore lead to more need for recovery from work.

Methodology: Data from a baseline questionnaire from a large study on fatigue at work was used. Participants were employees of 45 different companies in The Netherlands. Three populations were studied: A. day employees only, B. day workers with vocation-level education only, and C. workers with 26 to 35 hr/wk of work, which would include those working on 5-shift systems. The Need for Recovery scale used was derived from the Dutch Experience and Assessment of Work questionnaire. The scale was derived using statements such as “I find it hard to relax at the end of a working day” and “My job causes me to feel rather exhausted at the end of a working day.”

Scope of Work: The present study was designed to describe the magnitude of associations between working hours and need for recovery from work.

Sample Size: Population A: 5170, Population B: 2167, Population C: 815

Industry Sector: n/a

Major Limitations: No information on occupation. Healthy worker effect might be seen in workers who choose to work shifts. This would underestimate the effect.

Findings Directly Related to HOS (include page references):

Recovery/Restart Periods

In men, continuous Need for Recovery scores were significantly associated with working more than 40 hr per week compared with fewer hours per week, working 9 to 10 hr per day compared with working fewer hours per day, and working overtime frequently. Working ≤25 hr per week was also significant. These results were controlled for age, disease, job characteristics of physical, emotional, and psychological demands. Using dichotomous outcome for Need for Recovery (highest quartile vs. lowest quartile), results in men showed significant associations between high need for recovery and working 9 to 10 hr per day, working more than 40 hr per week, and working frequent overtime. No dose-response analyses were performed. Regarding shift work, three-shift workers were significantly more likely to need recovery time from work than day workers.

Author's conclusion: "The study showed that high working hours a day and high working hours a week generally went together with a higher need for recovery, confirming our hypothesis that day workers with many working hours a week report more need for recovery from work compared to employees working less hours a week. Extension of the working day, in terms of overtime work, was particularly associated with more need for recovery in both men and women." (p. 674)

Reviewer's Notes: This study, with a large sample, showed significant need for recovery from work in those working 9 to 10 hr a day, more than 40 hr per week, and overtime.

Reviewer: Susan Buchanan

Complete Title: Miyamoto, M., Shirai, Y., Nakayama, Y., Gembun, Y., and Kaneda, K. "An epidemiologic study of occupational low back pain in truck drivers." J Nippon Med Sch. 2000 Jun;67(3):186–90.

Abstract: The factors involved in occupational LBP occurring in professional drivers were investigated epidemiologically with questionnaires (92 items) including LBP symptoms, personal factors and occupational factors. The responses of 153 of 181 truck drivers who work in a large chemical industry corporation were analyzed after they had completely filled in questionnaires. As analysis of the results shows, the prevalence of LBP in 1 month of the survey was 50.3%. Correlating among data of personal factors and LBP, the prevalence of LBP was significantly higher in the drivers (odds ratio of 2.7) who answered "yes" to the item "shortage of spending time with family" than in the drivers who did not answer yes. The occupational factors, working load and working environment showed no correlation with the prevalence of LBP. In contrast, 3 items of the working format related significantly to the prevalence of LBP: irregular duty time (odds ratio of 3.0), short resting time (2.4), and long driving time in a day (2.0). Eighty-one of the 153 drivers (52.9%) pointed out the relationship between LBP and work, especially work which involves vibration or road shock. Our results and the results from previously published studies suggested that vibration is an obvious risk factor for LBP. From the viewpoint of prophylaxis, an improvement in working conditions reduces the incidence of drivers' LBP to some extent.

Methodology: Truck drivers who work for a large chemical industry corporation completed questionnaires. The questionnaire had 92 items with sections on LBP symptoms, personal factors, and occupational factors including working load, working environment, and working format.

Scope of Work: To investigate by use of questionnaires, the prevalence of LBP symptoms and its risk factors among truck drivers.

Sample Size: 153 completed questionnaires

Industry Sector: Truck drivers, no further characterization

Major Limitations: No information on participant recruitment. Were they volunteers who might be more likely to have symptoms? No information was given on job types or exposures of participants. They all worked for the same company so one might not be able to generalize these results. Details on risk factors were lacking: what do irregular duty time and short resting time mean exactly? Self-reported symptoms of back pain may not indicate medical condition.

Findings Directly Related to HOS (include page references):

Driver Health (General)

Lack of sleeping time was a risk factor for LBP but was not significant. Working load and working environment factors were not significant, although some associations were positive. Two working format factors were significant: irregular duty time and short resting time. Insignificant but positive working format factors were long driving time in a day, long driving time in a week, long working time in a day, irregular meal time, and long working time in a week. (See Table 4, p. 189.)

Reviewer's Notes: Despite the limitations noted above, this was a decent sized sample showing a significant relationship between LBP and irregular duty time and short resting time. Several other working format factors showed positive associations but were not significant. Overall this study suggests a relationship between driving hours in a day and LBP.

Reviewer: Susan Buchanan

Complete Title: Magnusson, M.L., Pope, M.H., Wilder, D.G., and Areskoug, B. "Are occupational drivers at an increased risk for developing musculoskeletal disorders?" Spine. 1996 Mar 15;21(6):710–7.

Abstract: Study Design: This study analyzed the role of exposure to driving and other covariates in reports of back, neck, and shoulder pain and resultant disability. Cohorts in Sweden and the United States were compared. Objectives: To establish the effect of mechanical and psychosocial factors in reporting back, neck, and shoulder pain and work loss. Summary of Background Data: There are numerous reports of a positive relationship between back pain and driving. However, exposure data are minimal. The influence of job satisfaction has not been assessed. Methods: The physical factors affecting reports of back, neck, and shoulder pain were investigated in a two-country cohort study of bus and truck drivers and sedentary workers. Vibration exposure was obtained by directly measuring the vibration imposed on the driver during a typical work day. Lifting exposure was attained by questionnaire. Cumulative exposure was computed based on work history. Musculoskeletal health information was based on a modified Nordic questionnaire, and other questionnaires recorded the physical and psychosocial aspects of the work environment. Results: Of the sample, 50% reported LBP, with no difference between countries. The highest risk factors (odds ratios) for back and neck pain were long-term vibration exposure, heavy lifting, and frequent lifting. A combination of long-term vibration exposure and frequent lifting carried the highest risk of LBP. Work loss from LBP was influenced by perceived job stress. Conclusions: Vibration (resulting from driving) and lifting cause back, neck, and shoulder pain, whereas inability to work seems affected by stress at work.

Methodology: Participants were recruited by personal contact with workers in several companies in Vermont and in Gothenburg, Sweden, who were male truck drivers or bus drivers. Sedentary workers served as the control group. Musculoskeletal health information was based on modified Nordic questionnaires (a standardized questionnaire used to assess musculoskeletal symptoms.) Another questionnaire had detailed questions about the work environment and the amount of lifting, sitting, standing, and driving on the job. Vibration levels during representative driving conditions were measured. The summed products of "average acceleration" × "exposure duration" represented the daily vibration dose for that driver. Long-term vibration exposure was calculated as the product of daily exposure dose and years on the job as drivers.

Scope of Work: To compare the effect of exposure to vibration on drivers' back, neck, and shoulder pain with those of control subjects in cohorts in two countries.

Sample Size: U.S.: 124, Sweden: 241

Industry Sector: Bus drivers and truck drivers; no further detail given

Major Limitations: Did not explain recruitment nor any detail on the participants. Did not measure awkward postures and seated exposure.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

"American truck drivers had a significantly higher daily exposure (to vibration) than bus drivers." (p. 9 of 16) "Those who reported LBP had a significantly higher total long-term vibration exposure than those who did not report LBP in those aged 35 to 45 years. Long-term exposure to vibration (equal to the vibration exposure over years in the profession) was the strongest predictor of length of sick leave because of LBP." (p. 9-10 of 16) "Significant single risk factors were . . . long-term vibration exposure." (p. 11 of 16)

Reviewer's Notes: Because this study did not elaborate on sampling and recruiting methods, it is difficult to judge its validity; however, results show that long-term exposure to vibration was a significant risk factor for LBP.

Reviewer: Susan Buchanan

Complete Title: Sokejima, S. and Kagamimori, S. “Working hours as a risk factor for acute myocardial infarction in Japan: case-control study.” BMJ. 1998 Sep 19;317(7161):775–80.

Abstract: Objective: To clarify the extent to which working hours affect the risk of acute MI, independent of established risk factors and occupational conditions. Design: Case-control study. Setting: University and general hospitals and routine medical examinations at workplaces in Japan. Subjects: Cases were 195 men aged 30 to 69 years admitted to hospital with acute MI during 1990 to 1993. Controls were 331 men matched at group level for age and occupation who were judged to be free of coronary heart diseases at routine medical examinations in the workplace. Main Outcome Measures: Odds ratios for MI in relation to previous mean daily working hours in a month and changes in mean working hours during previous year. Results: Compared with men with mean working hours of >7 to 9 hr, the odds ratio of acute MI (adjusted for age and occupation) for men with working hours of >11 hr was 2.44 (95% CI 1.26–4.73) and for men with working hours of ≥7 hr was 3.07 (1.77–5.32). Compared with men who experienced an increase of ≤1 hour in mean working hours, the adjusted odds ratio of MI for men who experienced an increase of >3 hr was 2.53 (1.34–4.77). No appreciable change was observed when odds ratios were adjusted for established and psychosocial risk factors for MI. Conclusion: There was a U-shaped relationship between the mean working hours and the risk of acute MI. There also seemed to be a trend for the risk of infarction to increase with greater increases in mean working hours.

Methodology: Case-control study (in Japan) of male patients with first MI, recruited from four hospitals. Controls were matched by occupation and recruited at their mandatory yearly workplace physical. Questionnaires were completed on working hours. Odds ratios for MI were adjusted for smoking, hypertension, DM, BMI, and hypercholesterolemia.

Scope of Work: To clarify the extent to which working hours affect the risk of acute MI.

Sample Size: 195 cases, 331 controls

Industry Sector: “Transport and Communications” was one of the occupational categories.

Major Limitations: Those who survived MI were interviewed. Those not surviving were excluded (history of work hours was not taken from surviving family members).

Findings Directly Related to HOS (include page references):

Time on Task

For the month before the MI, mean working day of ≥11 hr and a short working day (≤7 hr) were associated with a significantly increased risk of infarction compared with working 7 to 9 hr. (Table 3) When looking at the amount of increase in hours between the shortest amount of time worked in a month (in the previous year) compared with the month before the infarction, “there was a significant trend in the odds ratios increasing with greater increase in mean working hours.” (p. 778) Authors’ conclusion: “there seemed to be a trend for the risk of acute MI to increase with greater increases in working hours.” (p. 779)

Reviewer’s Notes: There was a significant increase in risk of MI with mean daily working hours of ≥11 hr. There was no increased risk for working 9 to 11 hr. The increase in odds ratio with increased CHANGE in mean working hours from shortest month to the month before MI may indicate that changes in the circadian rhythm may increase risk for MI. These results are not specific to truck drivers.

Reviewer: Susan Buchanan

Complete Title: Seshagiri, B. "Occupational noise exposure of operators of heavy trucks." Am Ind Hyg Assoc J. 1998 Mar;59(3):205–13.

Abstract: More than 400 measurements were taken across Canada to assess the noise exposure of truck operators. The exposure of the driver was evaluated using both 3-dB (Leq) and 5-dB (L5dB) exchange rates. Driving with windows closed and radio not operating resulted in the lowest exposure. The drivers' Leq ranged from 78 to 89 dBA, with a mean of 82.7 dBA; operating the radio increased the mean by 2.8 dB; driving with the driver's side window open increased the mean exposure by 1.3 dB; and driving with the window open and operating the radio resulted in an increase of 3.9 dB. Trucks with cabs mounted over the engine appeared to be quieter than standard trucks by about 2.6 dB. Operations on four-lane highways were 1.6 dB noisier than on two-lane highways, most likely as a result of higher speeds on the former. Long haul (city-to-city) operations on hilly terrain appeared to be quieter than on flat terrain by about 2.2 dB, again probably indicating the strong effect of speed. Regression analysis was used to obtain relationships between a number of variables such as Leq and L5dB. These measurements indicate that the exposure of a driver is almost certain to exceed the current threshold limit value for noise (85 dBA for 8 hr with a 3-dB exchange rate) when driving with the radio on and the driver's side window open. Comparable numbers in terms of L5dB are also reported.

Methodology: Eight trucking companies in seven areas of Canada were included in a survey of a variety of models, makes, and ages of tractors as well as routes that covered different types of terrain. Tests were conduced under four conditions: (1) all windows and vents closed, radio and CB not operating, (2) all windows and vents closed, radio operating, CB operating or not operating, (3) driver's side window open, radio and CB not operating, (4) driver's side window open, radio operating, CB operating or not operating.

Scope of Work: To evaluate the noise exposure of truck drivers under normal operating conditions.

Sample Size: 135 long-haul samples, 66 pick-up and delivery samples, and 29 sleeper berth samples

Industry Sector: Long-haul drivers

Major Limitations: n/a

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Personal samples showed that driving with the radio on and the windows closed resulted in an Leq of 85.5 dBA. Driving with the window open and the radio on resulted in an Leq of 86.6 dBA. Ten percent of the long-haul drivers exceeded an Leq of 90 dBA while 53% exceeded 85 dBA. (The mean level of exposure was 85 dBA.) "It is clear from this analysis that truck drivers incur a significant risk to their hearing depending on the operating conditions, in particular whether they routinely drive with the window open, and use their radio and/or CB at a relatively high volume." (p. 212) "The risk of hearing loss among drivers of extra-long duration trips is of concern." (p. 213)

Reviewer's Notes: This is a study performed specifically to determine whether the revised sound level limits for employees in Canada should apply to the trucking industry. Noise-induced hearing loss is determined by cumulative exposure, so this is an important study showing that truck drivers are likely exposed to damaging levels of noise. Additional hours on the job will affect the long-term hearing acuity of drivers.

Reviewer: Peter Orris

Complete Title: Robinson, G.S., Casali, J.G., Lee, S.E. Role of Driver Hearing in Commercial Motor Vehicle Operation: An Evaluation of the FHWA Hearing Requirement. FHWA Contract No. DTFH61-C-00172.

Executive Summary

The Federal Highway Administration (FHWA) currently requires that all interstate truck drivers have a certain minimal level of hearing in order to obtain a commercial driver's license. A research program was undertaken to determine whether this hearing requirement is necessary, and if so, whether the requirement is set at the correct audiometric level. This was a multi-part project. The first segment of the project consisted of an extensive literature review on the topics of CMV driving and hearing, the effects of occupational noise exposure, and truck-cab noise. Another extensive segment of the literature review concerned the effectiveness of the forced-whisper test, which is one of two methods by which the FHWA allows truck driver hearing to be tested. No firm conclusions could be reached on any of these topics based solely on the literature review, but several interesting research questions and needs were identified as a result thereof.

The next phase of the research project was an extensive task analysis. This began with a review of truck driving task analysis literature, very little of which took into consideration the role of hearing or noise in the driving task. A classical task analysis was then performed, beginning with structured interviews with 11 subject matter experts (SMEs) for truck driving. The consensus of these SMEs was that hearing is required in order to drive a truck safely. The specific results of the SME interviews were then used to compile a task analysis questionnaire. The questionnaire itself was reviewed by several experts and verified by extensive job observations of the truck driving task. The finalized questionnaire was distributed to 80 truck drivers, and the answers were used to compile a final list of hearing-critical truck driving tasks, as well as a list of mechanical problems which can be detected through the use of hearing. A further result of the questionnaire was a list of critical driving incidents involving hearing which had been experienced by drivers completing the questionnaires.

To determine the noise level in truck cabs, spectral measurements were taken for nine trucks under eight different conditions during actual commercial runs. Measurements were also taken of engine idle noise and noise in the sleeper-berth. These were compared with other, previous measurements to determine whether truck-cab noise is increasing or decreasing with model-year changes. Although these measurements demonstrated a higher overall noise level than did several recent studies, this study was performed under more realistic conditions than the aforementioned studies. When compared with older studies of truck-cab noise (15 to 30 years ago), these measurements actually showed a decrease. So truck-cab noise has decreased over the last 30 years, but perhaps not by as much as had been reported in some recent studies that considered only ideal conditions. The overall broadband sound pressure level (SPL) for these nine trucks was 89.1 dBA for eight conditions of highway speed driving. The sleeper-berth mean SPL was 81.6 dBA, while for the engine idle conditions, cab noise was 68.7 dBA. The highway-speed driving SPL of 89.1 dBA was very close to the OSHA permissible exposure limit of 90 dBA for an 8-hr day (although the trucking industry is not required to follow OSHA regulations).

Dosimetry was used to measure the noise doses experienced by 10 truck drivers during normal commercial runs of 8 to 18 hr. Doses were also measured for nine sleeper berths. Doses were calculated for 8-, 10-, and 24-hr periods for the truck cab, and for 5-, 10-, and 24-hr periods for the sleeper berth. The 10-hr doses for all trucks were less than 50% (the OSHA action level at which a hearing conservation program must be put into place in industry). When sleeper-berth doses were added in for 24-hr calculations, the doses exceeded the 50% level and approached the 100% level. These calculations mainly applied to team drivers, since they included sleeper-berth doses measured with the truck running at highway speeds.

Single drivers who spent sleeping time in the sleeper berth with the engine idling or shut off did not experience excessive noise doses in contemporary cabs, since the engine idle SPL was significantly less than the highway speed SPL. Sleeper-berth doses were so much lower than cab doses that drivers were encouraged to spend as much non-driving time as possible in the sleeper berth with the curtains closed in order to reduce their total noise exposure. One important consideration for the dosimeter measurements is that they included rest breaks, meal breaks, and refueling stops as set by the driver. The doses were therefore representative of the doses drivers received on a day-to-day basis.

In order to determine whether truck drivers experience a temporary decrement in hearing after a normal driving shift (known as temporary threshold shift or TTS), pre- and post-workday audiograms were performed for a group of 10 drivers. Results showed no such decrease, although there were two confounding factors which might account for the lack of TTS. First, due to scheduling constraints, drivers were not given advance notice of participation in the experiment, and thus were not informed to control their off-the-job noise exposure for 16 hr prior to the pre-work audiogram. Noise exposure during this critical time could have raised the threshold level for the pre-work audiogram, thus masking any TTS which might have occurred. Second, the post-work audiogram was given from 15 to 25 min after the end of the work shift due to driver availability and equipment warm-up time. A maximum delay of 2 min is preferred for laboratory TTS measurements, but delays of up to 25 min are not uncommon for field experiments such as this one. This delay could have allowed recovery from any TTS that actually occurred. Pre-work audiograms were available for another group of 20 drivers, resulting in a 30-driver sample for investigation of noise-induced permanent threshold shift (NIPTS). These data were compared with threshold data for non-noise exposed males of the same mean age. This comparison showed significantly higher thresholds for these 30 drivers (as compared with the non-noise exposed population data) at 3000, 4000, and 6000 Hz, but not at 500, 1000, or 2000 Hz (the three frequencies required to be tested by the FHWA if the audiometric test is used). As a result of the prevalence of noisy hobbies and previous occupations among both this group of drivers and the group completing questionnaires, no conclusions could be reached as to whether the NIPTS was caused by truck-cab noise.

Methodology: To determine the noise level in truck cabs, spectral measurements were taken for nine trucks under eight different conditions during actual commercial runs. Measurements were also taken of engine idle noise and noise in the sleeper berth. These were compared with other, previous measurements to determine whether truck-cab noise was increasing or decreasing with model-year changes.

Dosimetry was used to measure the noise doses experienced by 10 truck drivers during normal commercial runs of 8 to 18 hr. Doses were also measured for nine sleeper berths.

In order to determine whether truck drivers experience a temporary decrement in hearing after a normal driving shift (known as temporary threshold shift or TTS), pre- and post-workday audiograms were performed for a group of 10 drivers. Pre-work audiograms were available for another group of 20 drivers, resulting in a 30-driver sample for investigation of noise-induced permanent threshold shift (NIPTS). These data were compared with threshold data for non-noise exposed males of the same mean age.

Scope of Work: This research program was undertaken to determine whether the FHWA hearing requirement is necessary, and if so, whether the requirement is set at the correct audiometric level.

Sample Size: n/a

Industry Sector: Professional drivers

Major Limitations: Limited number of drivers and trucks tested

Findings Directly Related to HOS (include page references):

Other Study Findings

Measurements demonstrated a higher overall noise level than did several recent studies, this study was performed under more realistic conditions than the aforementioned studies. When compared with older studies of truck-cab noise (15 to 30 years ago), these measurements actually showed a decrease. So truck-cab noise has decreased over the last 30 years, but perhaps not by as much as had been reported in some recent studies that considered only ideal conditions. The overall broadband SPL for these nine trucks was 89.1 dBA for eight conditions of highway speed driving. The sleeper-berth mean SPL was 81.6 dBA, while for the engine idle conditions, cab noise was 68.7 dBA. The highway-speed driving SPL of 89.1 dBA was very close to the OSHA permissible exposure limit of 90 dBA for an 8-hr day (although the trucking industry is not required to follow OSHA regulations).

The 10-hr doses for all trucks were less than 50% (the OSHA action level at which a hearing conservation program must be put into place in industry). When sleeper-berth doses were added in for 24-hr calculations, the doses exceeded the 50% level and approached the 100% level.

Single drivers who spend sleeping time in the sleeper berth with the engine idling or shut off should not experience excessive noise doses in contemporary cabs, because the engine idle SPL is significantly less than the highway speed SPL.

There were significantly higher thresholds for these 30 drivers (as compared with the non-noise exposed population data) at 3000, 4000, and 6000 Hz, but not at 500, 1000, or 2000 Hz (the three frequencies required to be tested by the FHWA if the audiometric test is used). As a result of the prevalence of noisy hobbies and previous occupations among both this group of drivers and the group completing questionnaires, no conclusions could be reached as to whether the NIPTS was caused by truck-cab noise.

Reviewer's Notes: An excellent literature review and comprehensive small study. Cannot fully evaluate current exposure resulting from changing cab design.

Reviewer: Susan Buchanan

Complete Title: Soll-Johanning, H., Bach, E., and Jensen, S.S. "Lung and bladder cancer among Danish urban bus drivers and tramway employees: a nested case-control study." Occup Med (Lond). 2003 Feb;53(1):25–33.

Abstract: Background: The combustion of fossil fuels produces small amounts of mutagenic and carcinogenic compounds. We investigated the association between employment and lung and bladder cancer in Danish bus drivers and tramway employees. Methods: We carried out a nested case-control study of 153 lung and 84 bladder cancer cases, and 606 controls sampled in a cohort of 18,174 bus drivers or tramway employees employed in Copenhagen during the period 1900 to 1994. The cases and controls or their next of kin were interviewed about smoking, along with occupational and residential history. An exposure index based on which bus routes the bus drivers had mainly been driving was established. Relative risks (RRs) were estimated by conditional logistic regression. Results: The analysis showed decreasing risk for lung cancer with increasing years of employment as a bus driver (RR = 0.97 for each added year, 95% CI = 0.96–0.99). The air pollution index based on main bus for the bus drivers showed no positive correlation with risk.

Methodology: All people ever employed by the Copenhagen Traffic Company between 1900 and 1994 were included. Data on date of start and end of work periods were linked with the Central Population Register. All lung and bladder cancer cases identified by the Danish Cancer registry were contacted for a telephone interview. Cases were matched to 1 to 4 random controls from the original cohort based on year of birth. Exposure was characterized as "little diesel air pollution" before 1943, "moderate air pollution" from 1946 to 1958, and "substantive air pollution" from 1958 onward. Bus routes for individual drivers were obtained for analysis by GIS. This information was used to create an exposure index.

Scope of Work: A previous retrospective cohort study performed in this group (see secondary references) found increased lung cancer risk with duration of employment in urban bus drivers or tramway workers but did not control for smoking. The current study used the same database and controlled for confounders such as smoking, place of residence, and working history.

Sample Size: 18,174 bus drivers and tramway employees in original database. For this nested case-control study there were 153 lung cancer cases, 84 bladder cancer cases, and 606 controls.

Industry Sector: Bus drivers

Major Limitations: Exposures were estimated for urban work situations only. A substantial healthy worker effect would be expected in this design which would predispose to a negative result when evaluating association. Finally, the calculation of dose based on the assumption of an increasing intensity of exposure over a working lifetime might well produce a survivor effect mitigating or reversing a dose-response finding.

Findings Directly Related to HOS (include page references):

Time on Task

Increasing years of employment as a bus driver was significant association with decreasing risk of lung cancer.

Reviewer's Notes: This is a negative retrospective study of lung cancer risk and exposure to diesel exhaust with study limitations of power, healthy worker, and survivor effects rendering the result of interest but limited weight in rejecting a hypothesis of a causal connection between lung cancer and diesel exhaust.

Reviewer: Susan Buchanan

Complete Title: Steenland, K., Deddens, J., and Stayner, L. "Diesel exhaust and lung cancer in the trucking industry: exposure-response analyses and risk assessment." Am J Ind Med. 1998 Sep;34(3):220–8.

Abstract: Background: Diesel exhaust is considered a probable human carcinogen by the International Agency for Research on Cancer (IARC). The epidemiologic evidence rests on studies of lung cancer among truck drivers, bus drivers, shipyard workers, and railroad workers. The general public is exposed to diesel exhaust in ambient air. Two regulatory agencies are now considering regulating levels of diesel exhaust: the California EPA (ambient levels) and the Mine Safety Health Administration (MSHA) (occupational levels). To date, there have been few quantitative exposure-response analyses of diesel and lung cancer based on human data. Methods: We conducted exposure-response analyses among workers in the trucking industry, adjusted for smoking. Diesel exhaust exposure was estimated based on a 1990 industrial hygiene survey. Past exposures were estimated assuming that they were a function of (1) the number of heavy duty trucks on the road, (2) the particulate emissions (g/mi) of diesel engines over time, and 3) leaks from trucks' exhaust systems for long-haul drivers. Results: Regardless of assumptions about past exposure, all analyses resulted in significant positive trends in lung cancer risk with increasing cumulative exposure. A male truck driver exposed to 5 micrograms/m3 of elemental carbon (a typical exposure in 1990, approximately 5 times urban background levels) would have a lifetime excess risk of lung cancer of 1 to 2% above a background risk of 5%. Conclusions: We found a lifetime excess risk 10 times higher than the 1 per 1,000 excess risk allowed by OSHA in setting regulations. There are about 2.8 million truck drivers in the U.S. Our results depend on estimates about unknown past exposures, and should be viewed as exploratory. They conform reasonably well to recent estimates for diesel-exposed railroad workers done by the California EPA, although those results themselves have been disputed.

Methodology: Data used for this analysis were from a case-control study of decedents in the Teamsters Union. Smoking histories were obtained from next-of-kin. Job-specific elemental carbon measurements in the trucking industry were made (a surrogate for diesel exhaust). Estimates of past level of exposure were made based on changes in diesel engine emissions over time and on the increased use of diesel engines over time. Data on vehicle miles traveled by heavy duty trucks was obtained from the FHWA to estimate past exposure.

Scope of Work: To conduct an exposure-response analysis for diesel exposure and lung cancer.

Sample Size: 1,237 long-haul drivers, 297 short-haul drivers, 164 dockworkers, 88 mechanics, and 120 workers outside the trucking industry.

Industry Sector: Short- and long-haul drivers, mechanics, dockworkers, and controls outside the trucking industry without occupational diesel exposure.

Major Limitations: The exposures assigned to individual workers were crude estimates not based on measurements of actual exposure. Intrinsic in any risk assessment is the estimation error when evaluating exposures.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Results from a previous study using this database were reported here and showed that both short-haul and long-haul drivers had 3 to 4 times the residential background exposure to elemental carbon and that risk for lung cancer increased with cumulative exposure (Table I). Logistic regression for lung cancer and cumulative exposure showed that models with cumulative exposure in quartiles were significant at the highest level of exposure. "In summary, our data suggest a positive and significant increase in lung cancer risk with increasing estimated cumulative exposure to diesel exhaust among workers in the trucking industry." (p. 228)

Reviewer's Notes: This study used a large cohort as well as state-of-the-art exposure assessment methods to show both increased risk for lung cancer with exposure to diesel exhaust and a dose-response trend.

Reviewer: Susan Buchanan

Complete Title: Tuntiseranee, P., Olsen, J., Geater, A., and Kor-anantakul, O. “Are long working hours and shiftwork risk factors for subfecundity? A study among couples from southern Thailand.” Occup Environ Med. 1998 Feb;55(2):99–105.

Abstract: Objective: To estimate the effect of long working hours and shift work on time to pregnancy. Methods: Cross-sectional samples with retrospective data collection from two 700 bed hospitals at secondary to tertiary care level in Hatyai district, Songkhla Province, Thailand. The study was conducted from March 1995 to November 1995 among 1,496 pregnant women attending the antenatal clinics. Subfecundity was defined as time to pregnancy longer than 7.8, 9.5, or 12 months (time to pregnancy was calculated from the date at which the couples started having sexual relations without any contraception until last menstrual date). Results: The descriptive analyses were restricted to 1,201 planned pregnancies and the analytical part to 907 working women. Separate analyses on primigravid women were also done. Logistic regressions adjusted for age, education, body mass index, menstrual regularity, obstetric and medical history, coital frequency, and potential exposure to reproductive toxic agents, showed an odds ratio (OR) associated with female exposure to long working hours of 2.3 (95% CI 1.0–5.1) in primigravid and 1.6 (1.0–2.7) in all pregnant women. Male exposure to long working hours and shift work showed no association with subfecundity. The OR of subfecundity was highest when both partners worked >70 hr per week irrespective of the cut off point used OR 4.1 (95% CI 1.3–13.4) in primigravid women; OR 2.0 (95% CI 1.1–3.8) in all pregnant women). Conclusions: Long working hours is a risk factor for subfecundity especially for women. Shift work was not associated with subfecundity in this study.

Methodology: Data is from a consecutive sample of 1,496 pregnant women who received antenatal care at two large public hospitals. Using Thai women to study this issue was deemed favorable because some potential confounders had little variation in this population (most Thai women do not smoke, drink little alcohol or coffee, and many work under physically demanding conditions). A fecundity questionnaire was used which included information on the time the woman began to have regular intercourse without any contraception and other exposure factors of both partners. Working hours per week were stratified to 3 levels: <60, 61 to 79, >71.

Scope of Work: This study aimed at examining the problem of impaired fecundity (the ability to produce a pregnancy that survives to recognition) as a result of long working hours and shift work in southern Thailand.

Sample Size: 1496 Thai women

Industry Sector: n/a

Major Limitations: Due to sample population of pregnant women, infertile women were excluded so might have resulted in less significant results. No information on occupation.

Findings Directly Related to HOS (include page references):

Time on Task

Results of the model that included women’s working hours only (not couples’ working hours) showed that working >71 hr per week (compared with <60 and 61 to 70 hr per week) was a significant risk factor for time to pregnancy of >9.5 months. For the model including couples’ working hours, time to pregnancy was significantly increased when both couples worked >71 hr per week. Both of these models controlled for coital frequency.

“Woman and men working >71 hr per week had the highest percentage of subfecundity both among first pregnancies and the total sample, and shift work had a similar distribution of subfecundity in both groups for both men and women.” (p. 7 of 12)

“Our findings imply that long working hours could have an adverse effect on the fecundity of the couple which goes beyond the effect on libido and sexual activity.” (p. 10 of 12)

Reviewer’s Notes: This study suggests that working more than 71 hr per week is associated with a prolonged time to achieving pregnancy. Tests for dose response were not performed.

Reviewer: Susan Buchanan

Complete Title: van der Hulst, M.. "Long workhours and health." Scand J Work Environ Health. 2003 Jun;29(3):171-88. Comment in: Scand J Work Environ Health. 2003 Jun;29(3):167–9.

Abstract: This paper summarizes the associations between long work hours and health, with special attention for the physiological recovery and behavioral life-style mechanisms that may explain the relationship. The evidence for these mechanisms has not been systematically reviewed earlier. A total of 27 recent empirical studies met the selection criteria. They showed that long work hours are associated with adverse health as measured by several indicators (cardiovascular disease, diabetes, disability retirement, subjectively reported physical health, subjective fatigue). Furthermore, some evidence exists for an association between long work hours and physiological changes (cardiovascular and immunologic parameters) and changes in health-related behavior (reduced sleep hours). Support for the physiological recovery mechanism seems stronger than support for the behavioral life-style mechanism. However, the evidence is inconclusive because many studies did not control for potential confounders. Because of the gaps in the current evidence and the methodological shortcomings of the studies in the review, further research is needed.

Methodology: The review was limited to articles published in peer-reviewed psychological and medical journals in the English language published between January 1996 and June 2001. Criteria for review were studies which included working populations with at least some participants working 40 hr per week, work hours reported per day or per week, health status as outcome measures, statistical tests for association between extended hours and the outcome measures.

Scope of Work: To provide an up-to-date overview of recent empirical research on extended work hours and health and also an overview of the main conclusions of these studies.

Sample Size: The final selection included 27 articles reporting results from 28 studies in 26 independent samples.

Industry Sector: Various working populations

Major Limitations: The term "long work hours" had various meanings depending on the study.

Findings Directly Related to HOS (include page references):

Driver Health (General)

"Long work hours were associated with an increased risk of cardiovascular disease but a decreased risk of hypertension." "Working long hours was associated with increased risk of disability retirement and decreased sickness absence." "Long work hours appeared to be associated with impaired physical health and fatigue." "Regarding psychological health, long work hours were associated with social dysfunction and confusion, but associations with depression-related outcomes were mixed." "These results show that there is a good reason to be concerned about the possible detrimental effects of long work hours on health, in particular cardiovascular disease, diabetes, illnesses leading to disability retirement, subjectively reported physical ill health, and subjective fatigue." "It can be concluded that there is evidence of a link between long work hours and ill health, but there is a serious shortage of well-controlled studies that can confirm and strengthen the evidence." (p. 183)

Reviewer's Notes: This study is a review of the literature covering a very large topic. "These results show that there is a good reason to be concerned about the possible detrimental effects of long work hours on health, in particular cardiovascular disease, diabetes, illnesses leading to disability retirement, subjectively reported physical ill health, and subjective fatigue."

Reviewer: Susan Buchanan

Complete Title: Boshuizen, H.C., Bongers, P.M., and Hulshof, C.T. "Self-reported back pain in tractor drivers exposed to whole-body vibration." Int Arch Occup Environ Health. 1990;62(2):109–15.

Abstract: A postal questionnaire on symptoms of ill health and exposure to WBV was completed by 577 workers (response rate 79%) who were employed in certain functions by two companies 11 years before. The relationship between the occupational history of driving vibrating vehicles (mainly agricultural tractors) and back pain has been analyzed. The prevalence of reported back pain is approximately 10% higher in the tractor drivers than in workers not exposed to vibration. The increase is mainly due to more pain in the lower back and more pain lasting at least several days. A vibration dose was calculated by assigning each vehicle a vibration magnitude, estimated on the base of vibration measurements. The prevalence of back pain increases with the vibration dose. The highest prevalence odds ratios are found for the more severe types of back pain. These prevalence odds ratios do not increase with the vibration dose. This might be due to health-related selection which is more pronounced for severe back pain than for back pain in general. The two components of the vibration dose, duration of exposure and estimated mean vibration magnitude, have also been considered separately. Back pain increases with duration of exposure but it does not increase with the estimated mean magnitude of vibration. This is probably due to the inaccuracy of this estimate. The higher prevalence of back pain in tractor drivers might be (partly) caused by WBV, but prolonged sitting and posture might also be an influence.

Methodology: The study population consisted of workers employed by two state companies; 577 workers responded to a mailed questionnaire containing items on exposure to WBV, symptoms of musculoskeletal disease, and potential confounders. Vibration exposure was estimated using measurements taken at the two companies.

Scope of Work: This study investigates the prevalence of back pain in drivers of agricultural vehicles in relation to past exposure to WBV.

Sample Size: 577 drivers

Industry Sector: Tractor drivers

Major Limitations: No information on how study population was selected. Prevalence of back pain was self-reported.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Three types of vibration exposure variables were used. For vibration dose expressed as total years of exposure multiplied by measured vibration magnitude, LBP, frequent or long lasting LBP were both significant at all levels of exposure and increased with increasing exposure. A significant dose-response trend was seen for the three most common types of back pain. (Table 3, p. 112 and text p. 111) For vibration dose expressed as vibration magnitude correcting for duration of exposure and other confounders, frequent or long-lasting LBP were significantly associated with higher doses of vibration. (Table 4, p. 112) Vibration exposure measured in years of full-time exposure showed generally higher but insignificant odds ratios for back pain with increased exposure. (Table 5, p.113)

Reviewer's Notes: There is a dose-response trend of more frequent back symptoms with increasing duration of exposure to vibration. This should not be affected by actual level of vibration determined by truck or seat type, or road conditions. The published abstract of this study does not adequately reflect the data contained in the tables.

Primary Reviewer: Susan Buchanan

Complete Title: Caruso, C.C., Lusk, S.L., and Gillespie, B.W. "Relationship of work schedules to gastrointestinal diagnoses, symptoms, and medication use in auto factory workers." Am J Ind Med. 2004 Dec;46(6):586–98.

Abstract: Background: GI complaints are common in shift workers. This study examines the relationship between work schedules and GI symptoms, medications, and diagnoses. Methods: In a cross-sectional survey of 343 U.S. auto factory workers, four work schedule variables were examined: assigned shift, number of hours worked, number of night hours, and schedule variability. Multiple regression tested the relationship between GI outcomes and work schedule variables while controlling for covariates. Results: The evening shift was associated with more GI symptoms and GI diagnoses. Unexpectedly, more consistent work times were associated with having a GI diagnosis. As schedule variability increased the probability of GI medication use increased in low noise exposure. Conclusion: Findings suggest that evening shift and widely varying work start and end times may increase risks for GI disturbances.

Methodology: A convenience sample of auto workers in the Midwest United States. Participants completed a 20-page questionnaire which was designed for a larger cross-sectional study. This study used data on GI risk factors, specifically demographics, smoking, noise exposure, ASA and NSAID use, and stress. Work hours were documented using clock-in and clock-out records for 1 month.

Scope of Work: To examine the relationship between work schedules (shift work and overtime) and self-reported GI symptoms, GI medication use, and GI diagnoses.

Sample Size: 343 workers in one auto factory

Industry Sector: Auto factory workers who were skilled or unskilled hourly wage earners

Major Limitations: No information on how participants were recruited. Did only those with health problems volunteer? Healthy worker effect: inclusion criteria excluded those who had worked at the plant for less than 5 years. Symptoms were self-reported. The significant GI outcome in this study was GI medication use, not diagnoses or symptoms. Is this an adequate marker for GI disease?

Findings Directly Related to HOS (include page references):

Time on Task

a. GI symptoms: significant increase in symptoms for evening shift and insignificant increase after 30 hr/month of night work. b. GI diagnosis: significant increase in GI diagnosis with schedule variability and evening shift. c. GI medication use: significant increase in GI med use with clock-out variability and combined clock-in and-out variability over a 7-day period. "a 4-hr increase in clock-out variability over the 7-day period increased the odds for GI medication use by 30." (p. 592)

"Over the 28-day period, 40 extra hours of work (or an additional 10 hr per week) increased the odds for GI medication use by 23%." (p. 593)

"Total number of hours worked showed only a modest positive relationship with GI medication use, and no relationship with GI symptoms or diagnosis." (p. 595)

"Findings from the current study suggest that time of work (day vs. evening) and the consistency of the schedule may have a greater influence on these GI outcomes than overtime." (p. 595)

Reviewer's Notes: Schedule variability, evening shift, and number of hours worked per week are significantly associated with adverse GI outcomes.

Reviewer: Susan Buchanan

Complete Title: Boffetta, P. and Silverman, D.T. "A meta-analysis of bladder cancer and diesel exhaust exposure." Epidemiology. 2001 Jan;12(1):125–30.

Abstract: The aim of this study is to review and summarize the available epidemiologic studies of bladder cancer and occupational exposure to diesel exhaust. We retrieved relevant studies and abstracted their characteristics and results. We assessed the heterogeneity of the results to decide whether to perform a fixed-effects model meta-analysis. We identified 35 relevant studies. No overall meta-analysis was performed because of heterogeneity in results. Results of railroad workers (N = 14) suggested an increased occurrence of bladder cancer, but we did not conduct a meta-analysis. The summary relative risk (RR) among truck drivers was 1.17 (95% CI = 1.06–1.29, 15 studies) and that among bus drivers was 1.33 (95% CI = 1.22–1.45, 10 studies). Ten studies considered diesel exhaust exposure based on a job exposure matrix or a similar approach; the summary relative risk for these studies was 1.13 (95% CI = 1.00–1.27). A positive dose-response relationship was suggested by 10 of the 12 studies that provided relevant information. The summary relative risk for high diesel exposure was 1.44 (95% CI = 1.18–1.76). There was some evidence of publication bias, however, with a lack of small studies with null or negative results. Our review suggests that exposure to diesel exhaust may increase the occurrence of bladder cancer, but the effects of misclassification, publication bias, and confounding cannot be fully taken into account.

Methodology: Searched epidemiologic literature for studies on cancer after exposure to diesel exhaust and for studies on occupational risk factors for bladder cancer. Concentrated on 5 occupational groups including truck drivers.

Scope of Work: To summarize available results of epidemiologic studies of the association between occupational exposure to diesel exhaust and occurrence of urinary bladder cancer.

Sample Size: 29 studies on bladder cancer and exposure to diesel exhaust

Industry Sector: Truck drivers, no further characterization

Major Limitations:

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Fifteen results were available for truck drivers. Exposure was characterized by either years of employment or job exposure matrix. For exposure to diesel exhaust characterized as "high," relative risk was 1.44 and significant. For "any exposure," relative risk was 1.23 and significant. See Table 5. "Out of 12 results for 'heavy exposure,' 10 were higher than their corresponding results for 'any exposure,' and only one of the remaining was lower." (p. 129)

Reviewer's Notes: Meta-analysis showing positive evidence for increased risk of bladder cancer among truck drivers with "any exposure" to diesel exhaust. Truck drivers with "high" exposure were significantly more likely to have bladder cancer than those with lower levels of exposure.

Reviewer: Susan Buchanan

Complete Title: Lings, S. and Leboeuf-Yde, C. “Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992–1999.” Int Arch Occup Environ Health (2000);73: 290–297.

Abstract:

Objectives: A previous extensive review of the literature including that from the middle of 1992 concluded that WBVs may contribute to low back pain, but that the exposure-response relationship had not been clarified. We reviewed the literature of the past 7 years to find out: (i) whether there is evidence in the recent epidemiological literature for a causal association between WBV and LBP, and (ii) if there is evidence in the recent literature for a dose-response relationship between WBV and LBP. Methods: All relevant epidemiological articles, which were obtained through a search in the databases MEDLINE, OSH-ROM, and TOXLINE, and through personal communication, were reviewed independently by the two authors, using a checklist. Results: Twenty-four original articles concerning the association between WBV and the lower back were retained for use. Only seven articles passed our predetermined quality criteria. Of the seven reports, one showed increased frequency of lumbar prolapse in occupational drivers, and six showed LBP to be more frequent in WBV-exposed groups. Only two of the four articles reporting on dose showed a dose-response association. Conclusions: Despite the lack of definite evidence, we found sufficient reasons for the reduction of WBV-exposure to the lowest possible level. If new knowledge is to be produced, good prospective studies with repeated measurements of exposure, analyses of work postures, and clear definitions and subgroupings of LBP are needed. Other research in this field should be given up, and the resources used for more important issues, as the size of the problem of WBV is probably on the decrease because of the technical prophylactic developments that are already in progress.

Methodology: Literature review of MEDLINE, OSH-ROM, and TOXLINE of all original epidemiological articles published from 1992-1999. They were reviewed by the two authors, independently using predetermined quality criteria.

Scope of Work: To conduct a review of the literature on WBV and LBP since the issue was last reviewed in 1992. Questions addressed were: Is there evidence for a definite association between WBV and LBP? Is there evidence for a dose-response relationship between WBV and LBP?

Sample Size: 24 original reports were identified: 21 passed initial screening, 7 studies fulfilled at least 5 of the 6 quality criteria.

Industry Sector: Various

Major Limitations: Authors seemed a little opinionated, may have had an agenda

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Six reports showed LBP to be more frequent in study groups and one showed increased frequency of hospitalization for disc herniation in drivers. Of the four studies on dose-response, two showed an association. “. . . despite at least 24 epidemiological publications addressing the question, the evidence still remains weak.” (p. 291)

Authors’ conclusion: “The six reports that best fulfilled our quality criteria were predominantly in favour of a positive association between WBA and LBP . . . Hence it can still be concluded that here is probably an association between WBV and LBP,” (but not causality) "Existing knowledge yields sufficient reasons for reducing exposure to the lowest possible level." (p. 296)

Reviewer's Notes: Although the authors give mixed conclusions about the effect of WBV on LBP, most of the studies included in the literature review found positive associations. However, evidence for dose-response was weak.

Reviewer: Peter Orris

Complete Title: Jensen, Marianne V. Tuchsen, F., and Orhede, E. "Prolapsed Cervical Intervertebral Disc in Male Professional Drivers in Denmark, 1981–1990: A Longitudinal Study of Hospitalizations." Spine 1996, October 21(20): 2352–2355.

Abstract: Study Design: This study of professional drivers is a part of a longitudinal record linkage study of all economically active men in Denmark, identified on January 1, 1981. Information about the main occupation was identified in 1980. The cohort was followed for first hospitalization with prolapsed cervical intervertebral disc until December 31, 1990. Objectives: To examine the risk of prolapsed cervical intervertebral disc in all Danish professional drivers, and to analyze exposures of the male drivers in a sample of all Danish male drivers. Methods: A standardized hospitalization ratio was calculated for each subgroup of drivers using all economically active people as the standard. Additional exposure information was extracted from a national survey on work environment. Almost all men in occupations involving professional driving had a statistically significant elevated risk of being hospitalized with prolapsed cervical intervertebral disc. Conclusions: Professional driving is a risk factor for prolapsed cervical intervertebral disc.

Methodology: Methods: This study of professional drivers is a part of a longitudinal record linkage study of all economically active men in Denmark, identified on January 1, 1981. Information about the main occupation was identified in 1980. The cohort was followed for first hospitalization with prolapsed cervical intervertebral disc until December 31, 1990. A standardized hospitalization ratio was calculated for each subgroup of drivers using all economically active people as the standard. Additional exposure information was extracted from a national survey on work environment.

Scope of Work: Only a few studies on occupation and prolapsed cervical intervertebral disc have been published. These studies suggest that professional driving may be a risk factor for development of prolapsed cervical intervertebral disc. Drivers are exposed to WBVs, heavy lifting, and a sedentary position. Other potential exposures are accelerations and decelerations and whiplash accidents. Such exposures may be involved in the causation of prolapsed cervical intervertebral disc.

Sample Size: 1.3 million economically active men in Denmark

Industry Sector: Various

Major Limitations: Unable to separate WBV from other musculoskeletal stressors on drivers

Findings Directly Related to HOS (include page references): **Driver Health (General)**

Almost all men in occupations involving professional driving had a statistically significant elevated risk of being hospitalized with prolapsed cervical intervertebral disc.

Reviewer's Notes: An objective prospective study identifying professional driving as a risk factor for the development of prolapse of a cervical intervertebral disc.

Reviewer: Susan Buchanan

Complete Title: Gustavsson, P., Plato, N., Hallqvist, J., Hogstedt, C., Lewne, M., Reuterwall, C., and Scheele, P. "A population-based case-referent study of myocardial infarction and occupational exposure to motor exhaust, other combustion products, organic solvents, lead, and dynamite. Stockholm Heart Epidemiology Program (SHEEP) Study Group." Epidemiology. 2001 Mar;12(2):222–8.

Abstract: This case-control study investigated the risk of MI from occupational exposure to motor exhaust and other combustion products. We identified first-time, nonfatal MIs among men and women 45 to 70 years of age in Stockholm County from 1992 through 1994. We selected referent subjects from the population to match the demographic characteristics of the cases. A lifetime history of occupations was obtained by questionnaire. The response rate was 81% for the cases and 74% for the referents, with 1,335 cases and 1,658 referents included in the study. An occupational hygienist assessed occupational exposures, coding the intensity and probability of exposure for each subject. We adjusted relative risk estimates for tobacco smoking, alcohol drinking, hypertension, diabetes mellitus (DM), being overweight, and physical inactivity at leisure time. The relative risk of MI was 2.11 (95% CI = 1.23–3.60) among those who were highly exposed and 1.42 (95% CI = 1.05–1.92) among those who were intermediately exposed to combustion products from organic material. We observed an exposure-response pattern, in terms of both maximum exposure intensity and cumulative dose. Exposure to dynamite and organic solvents was possibly associated with an increased risk. The other exposures were not consistently associated with MI.

Methodology: Case-control study of first-time MI. Cases were identified from intensive care units in Stockholm County. Controls were selected from a computerized population register and were matched according to sex, age, and hospital catchment area. Subjects completed questionnaires on occupational history. A job exposure matrix was created by industrial hygienists using unpublished and published occupational hygiene reports, personal contacts and professional experience to quantify intensity of exposure using estimated exposure prevalence within each occupation (in terms of annual average of 8-hr work day exposures to motor exhaust.) Relative risks were adjusted for smoking, alcohol intake, hypertension, weight, DM, and physical inactivity.

Scope of Work: To investigate the risk of MI from occupational exposure to motor exhaust and other combustion products.

Sample Size: 1,335 case and 1,658 controls

Industry Sector: Did not specify

Major Limitations: Those who survived MI were interviewed. Those not surviving were excluded (history of exposure not taken from surviving family members). Exposures to exhaust were estimated, not measured. Did not control for cholesterol results. Did not specify type of exhaust.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

(Actual journal page numbers are not given in this on-line document.) Working conditions: There was a non-significant elevation of relative risk of MI with moderate exposure to motor exhaust. No dose response trend was seen. There was a significantly increased relative risk of MI with high or intermediate exposure to combustion products, (besides motor exhaust). The same results were found when cumulative exposure was estimated. (See Tables 2 and 4.)

"We found some indications of an increased risk of MI in association with exposure to motor exhaust, but no firm evidence of an exposure-response relation."

Reviewer's Notes: The results are suggestive of increasing MI risk with cumulative exposure to motor exhaust.

Reviewer: Susan Buchanan

Complete Title: Chen, J.C., Dennerlein, J.T., Shih, T.S., Chen, C.J., Cheng, Y., Chang, W.P., Ryan, L.M., and Christiani, D.C. "Knee pain and driving duration: a secondary analysis of the Taxi Drivers' Health Study." Am J Public Health. 2004 Apr;94(4):575–81.

Abstract: Objectives: We explored a postulated association between daily driving time and knee pain. Methods: We used data from the Taxi Drivers' Health Study to estimate 1-year prevalence of knee pain as assessed by the Nordic musculoskeletal questionnaire. Results: Among 1,242 drivers, the prevalence of knee pain, stratified by duration of daily driving (≤6, >6 through 8, >8 through 10, and >10 hr), was 11%, 17%, 19%, and 22%, respectively. Compared with driving 6 or fewer hr per day, the odds ratio of knee pain prevalence for driving more than 6 hr per day was 2.52 (95% CI = 1.36–4.65) after adjustment for socioeconomic, work-related, and personal factors in the multiple logistic regression. Conclusions: The dose-related association between driving duration and knee pain raises concerns about work-related knee joint disorders among professional drivers.

Methodology: Taxi drivers in Taipei city were recruited during free government physical exams. Questionnaires were completed which included information on daily driving hours, among other work factors, and presence of knee pain in the previous 12 months.

Scope of Work: To test the hypothesis that prolonged driving is associated with increased knee pain among taxi drivers.

Sample Size: 1,242 taxi drivers (of at least 1 years' duration)

Industry Sector: Taxi drivers

Major Limitations: Used self-reports of knee pain. Presence of pain does not necessarily indicate a medical condition.

Findings Directly Related to HOS (include page references):

Shifts/Time of Day/Circadian

Workers with >10 hr of daily driving had significantly increased risk of knee pain. There was a dose response in history of knee pain and daily driving times of ≤6 hr, 6 to 8 hr, 8 to 10 hr, and >10 hr (all significant) when controlled for age, gender, BMI, income, other demographics, and physical exertion during work and leisure time, and professional seniority. No associations were found between knee pain and vehicle manufacturers or engine sizes. Authors' conclusion: "Our exploratory analyses of the TDHS (Taxi Drivers' Health Study) baseline data revealed a strong and robust association between long driving times and knee pain. The public health impact of work-related knee pain among professional drivers could be substantial."

Reviewer's Notes: Agree with previous quote.

Reviewer: Susan Buchanan

Complete Title: Barton, J. and Folkard, S. "Advancing Versus Delaying Shift Systems." Ergonomics 1993;36(1-3):59–64.

Abstract: Two-hundred sixty-one shift workers from a range of UK industrial and service organizations took part in a study to determine the impact of the direction of shift rotation on the health and well-being of the individuals concerned. All the systems were continuous, rotating over three shifts. Systems were classified according to whether they delayed (i.e., rotated in a forward direction) or advanced (i.e., rotated in a backward direction). In addition, advancing systems were divided into those which incorporated a quick return (i.e., a break of only 8 hr when changing from one shift to another) and those which did not. The results add some support for the use of delaying as opposed to advancing systems, and highlight the detrimental affects of incorporating a quick return into an advancing system.

Methodology: All subjects completed the Standard Shift Work Index. ANCOVA was performed to determine the effect of the direction of shift rotation on each outcome measure.

Scope of Work: To examine the relative effect of advancing or delaying systems on shift workers.

Sample Size: A total of 261 industrial and service shift workers from a range of occupations took part in the study

Industry Sector: Shift workers from steel industry, power industry, post office, police force, and air traffic control officers

Major Limitations: There was no information given on the sampling method, whether the participants were voluntary or randomly selected.

Findings Directly Related to HOS (include page references):

Shifts/Time of Day/Circadian

Compared with the delayed rotating shift system, workers on the advancing system were significantly more likely to complain of digestive and cardiovascular disorders, chronic fatigue, and cognitive anxiety. (See Table 1, p. 61.)

"Comparing advancing systems with and without a quick return produced few significant differences, yet overall, it was the former who reported poorer physical health." (p. 63)

"In conclusion it would appear that the critical feature may not be related entirely to the direction of rotation but to a combination of direction and the length of break when changing from one shift to another." (p. 64)

Reviewer's Notes: This article adds to the body of literature associating a change in sleep schedule (a.k.a. circadian rhythm) with GI and cardiovascular effects.

Reviewer: Susan Buchanan

Complete Title: Morgan, L., Arendt, J., Owens, D., et al. "Effects of the endogenous clock and sleep time on melatonin, insulin, glucose and lipid metabolism." J Endocrin 1998;157:443–451.

Abstract: This study was undertaken to determine whether the internal clock contributes to the hormone and metabolic responses following food, in an experiment designed to dissociate internal clock effects from other factors. Nine female subjects participated. They lived indoors for 31 days with normal time cues, including the natural light and darkness cycles. For 7 days they retired to bed from 0000 to 0800. They then underwent a 26-hr 'constant routine' (CR) starting at 0800 h, being seated awake in dim light with hourly 88 Kcal drinks. They then lived on an imposed 27-hr day for a total of 27 days. A second 26-hr CR, starting at 22 hr was completed. During each CR salivary melatonin and plasma glucose, triglyceride (TAG), non-essential fatty acids (NEFA), insulin, gastric inhibitory peptide (GIP) and glucagons-like peptide-1 (GLP-1) were measured hourly. Melatonin and body temperature data indicated no shift in the endogenous clock during the 27-hr imposed schedule. Postprandial NEFA, GIP and GLP-1 showed no consistent effects. Glucose, TAG, and insulin increased during the night in the first CR. There was a significant effect of both the endogenous clock and sleep for glucose and TAG, but not for insulin. These findings may be relevant to the known increased risk of cardiovascular disease amongst shift workers.

Methodology: Subjects were observed for 31 days and were required to live on an imposed 27-hr day cycle. Activity was monitored with wrist monitors and rectal temps were recorded. Blood levels for triacylglycerol, insulin, and glucagon-like peptide. Salivary melatonin was measured.

Scope of Work: To determine to what extent the internal clock contributes to the hormonal and metabolic responses following a meal.

Sample Size: 9 female undergraduates

Industry Sector: n/a

Major Limitations: Testing was performed in experimental conditions which might not reflect real life scenarios.

Findings Directly Related to HOS (include page references):

Shifts/Time of Day/Circadian

"Dissociation of the internal clock and sleep in the second constant routine leads to a dampening of the peak response to glucose and the appearance of two comparable peaks, suggesting a 'spreading' of glucose intolerance such that it occurs at two periods of the day." (p. 448–449) "The present study has shown for the first time that the length of wakefulness also has an effect on glucose tolerance, independent of any circadian rhythm or sleep itself." (p. 449)

Reviewer's Notes: This group previously reported that immediately after a simulated 9-hr advance, such as might be found in rotating shift work, postprandial insulin and glucose responses to a standard mixed meal were significantly greater than to the same meal at the same external clock time before the phase shift. The changes were suggestive of insulin resistance, a risk factor for cardiovascular disease.

This study takes this issue a step further and tries to separate out the possible effect of a circadian rhythm change. Results showed that insulin resistance indeed worsened with a longer sleep-wake cycle but was independent of changes in the internal clock or circadian rhythm.

Reviewer: Susan Buchanan

Complete Title: Scott, A. "Shift Work and Health." Primary Care Dec 2000;27(4):1057–1078.

Abstract: Night work and rotating shift work disrupt the circadian timing system. This disruption may produce significant deleterious symptoms in some workers. Certain medical conditions may be aggravated by shift-work scheduling, and shift workers are at increased risk of experiencing cardiovascular, GI, and reproductive dysfunction. Vulnerable individuals may develop clinical depression when working shifts. Primary care practitioners may intervene by providing medical surveillance and education programs for shift-working patients and their families.

Methodology: Written as a chapter with 166 references. It is not original research but is an excellent review of the current literature up to 2000.

Scope of Work: This is a chapter on Occupational and Environmental Medicine in a hard bound journal. It offers an overview of circadian rhythms and the health effects of night work and sleep deprivation, and offers a review of specific medical disorders associated with shift work.

Sample Size: n/a

Industry Sector: n/a

Major Limitations: This is not original research. It assumes validity of its references.

Findings Directly Related to HOS (include page references):

Shifts/Time of Day/Circadian:

Circadian rhythm: ". . . each time the work schedule rotates, for a period of time after the time shift, the circadian system will be in a desynchronized state." (p. 1059)

Shift-work intolerance: "Up to 20% of shift workers may have a disproportionate number of symptoms of illness when assigned to chronobiologically poorly designed shift-work schedules involving night work." (p. 1061) "Specific factors that affect shift work tolerance include: . . . rotating or fixed, number of nights worked consecutively, frequency of weekends off, length of shift and starting time, overtime requirements, predictability of schedule." (p. 1061)

GI Disorders: "Gastrointestinal dysfunction is common in shift workers. . . . Some studies have not found an increased incidence of peptic ulcer disease in shift workers, but the majority of studies addressing this outcome have. Including non-English reports, 16 of 24 studies evaluating PUD and shift work found shift workers to be at greater risk of developing PUD than day workers. . . . Circadian rhythm disruption also contributes to shift-work related GI dysfunction." (p. 1062)

Cardiovascular morbidity: "Although there are studies that have not found changes in lipid profiles related to shift work, a recent thorough review of this research concluded that the better studies do indicate that shift workers have somewhat higher levels of cholesterol as well as triglycerides." "Although early studies concluded shift work was not associated with an increase in CVD, most of the more recent, better epidemiologically designed studies have found an increased risk of CVD." (p. 1063)

Reproductive Health: Studies quoted showed shift work and rotating shift work to be associated with higher prematurity rate, low birth weight, spontaneous abortion, and decreased fertility rate." (p. 1064-65)

Exacerbation of Medical Disorders: “Shift work also may aggravate certain medical disorders related to circadian rhythm disruption, psychosocial stress, or sleep deprivation. Conditions that may be exacerbated or aggravated by irregular schedules or night work and are therefore potential contraindications for shift work include: GI disorders, DM, epilepsy, cardiovascular disease, psychiatric disorders, sleep disorders, reproductive dysfunction.” (p. 1066)

Reviewer’s Notes: This chapter, with 166 references, confirms the multiple health issues related to shift work and rotating shift work including GI, cardiovascular, and reproductive health.

SUMMARY OF FINDINGS OF LITERATURE

The review of the available literature has excluded the end points of fatigue, accidents, and road safety. The available information has reviewed topics concerning driver health, with emphasis on chronic conditions.

The literature indicates lung cancer is likely caused by exposures to diesel exhaust and the longer that exposure lasts the more likely it is that a cancer will develop. Though the evidence for exposure as a truck driver causing bladder cancer is less robust than that for cancer of the lung, it remains likely that there is such a relationship and that it is governed by a positive dose-response curve.

The literature offers evidence that cardiovascular disease is caused in part by truck driving and its risk increases with the duration of this activity and the disruption of the sleep cycle.

The literature indicates that it is clear based on exposure assessments and the knowledge of the relationship between noise and hearing loss that this could well be a result of a working lifetime as a driver with increasing likelihood based on duration of exposure depending on truck design. This effect would be mitigated by improvement in cab design reported to be occurring with a consequent reduction in the intensity of noise that reaches the driver.

The evidence concerning a relationship between WBV and musculoskeletal effects, such as LBP syndrome, relies primarily on self-reporting and application of risks derived from other environments. There are several studies available that contain objective evidence of vertebral pathology related to an occupation as a professional driver. The available literature supports the hypothesis that there is likely a causative relationship between professional driving and a variety of vertebral disorders as well as LBP syndrome. While it is logical to assume, and the literature suggests, a role for WBV in the genesis of these disorders, it cannot be established based on current published materials.

The literature related to CMV driving and other musculoskeletal disorders suffers from the same limitations and while a causative relationship is logical it can only be viewed as suggestive within this context.

The literature indicates that GI disorders would be expected to be impacted by varying shift assignments and disruption to normal circadian rhythm. While the information currently available documents an increase in symptoms, it is inadequate to implicate the specific risk factors that impact on these symptoms.

The literature suggests, but does not establish, that disruption of circadian rhythm may have negative impacts on the general health status of workers. The stabilization of shift especially when stabilized to a day schedule appears to have a beneficial effect on subjective health complaints though stabilizing to an evening or night schedule may not provide the same benefit.

Finally, the literature does not contain definitive information concerning the relationship between reproductive health and duration of driving, nor on the effects of prolonged work hours or increased driving time from 10 to 11 hr while decreasing overall work time from 15 to 14 hr on the general health of workers. No data are available concerning the effects of allowing for increased sleep time from 6 to 8 hr in an adult working population.

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LITERATURE REVIEW—FATIGUE

According to the Scope of Work, the literature to be reviewed in Task 2 pertains to "*hours of service (HOS) and commercial vehicle operator performance and fatigue,* especially as they pertain to driver health. The purpose of this facet of the literature review is to provide information that clearly discusses in a scientific, experimental, qualitative, and quantitative way the relationship between the hours a person works, drives, and the structure of the work schedule (on-duty/off-duty cycles, time on task, especially time in continuous driving, sleep time, etc.) and the impact of CMV driver fatigue and performance."

PROCESS AND METHODOLOGY

The TRANSPORT database from the University of Toronto library system was used for the literature search. The key resource within the database is Transportation Research Information Services (TRIS) from TRB. TRANSPORT is a bibliographic database of transportation research and economic information. It is produced by the 25-nation Organisation for Economic Co-operation and Development (OECD), headquartered in Paris, together with the United States' TRB and the 31 nations of the European Conference of Ministers of Transport (ECMT). TRANSPORT combines the following databases: TRIS from TRB includes 300,000 bibliographic citations, most with abstracts, of research information on all surface transportation modes, air transport, and highway safety. International Road Research Documentation (IRRD) from OECD contains 200,000 abstracts on highway research provided by OECD member countries. TRANSDOC from ECMT contains 37,000 abstracts of transportation economics literature as well as bibliographic records provided by the International Union of Railways (UIC).

A search for articles after 1995 was performed on the database using the following terms:

- CMV operators and fatigue
- CMV operators, fatigue, and the following
  - driving performance
  - driving hours, time on task, duration of work-weeks
  - length of sleep time, sleep deprivation
  - shift work, schedule regularity, schedule irregularity
  - sleep deprivation countermeasure (including naps)
  - HOS regulations
  - schedules, shift rotation, multi-day shifts
  - operational and performance models
  - alertness, fatigue
  - distraction and reaction time
- Drivers and fatigue
- Drivers, fatigue, and the following
  - Driving performance
  - Driving hours
  - Length of sleep time, sleep deprivation
  - Shift work
  - Sleep deprivation countermeasure (including naps)
  - Alertness, fatigue
  - Distraction and reaction time
- CMV operators and
  - HOS
  - Hours of work
  - Work rest schedules
  - Workload
  - Sleep schedules
  - Rest periods
  - Performance (as opposed to '"driving performance")

SELECTION CRITERIA

The following are a list of references from the scientific and technical literature concerning HOS and CMV operator performance and fatigue, especially as they pertain to driver health. The references focus on experimental studies or surveys. Literature reviews and papers focusing on policy have been excluded from this list. Papers focused specifically on crashes as well as sleep deprivation countermeasures, harmful/toxic substances, technological approaches to CMV driver alertness management, and distraction and reaction time have also been excluded from this list.

Primary Sources

Primary references met the following selection criteria. Each reference had to address truck driver performance (on road or in driving simulators) and include some measure of performance (vehicle control or critical incidents) in association with driving. Studies had to involve drivers on typical work-rest schedules, that is, they involved extended hours of driving, driving in a sleep-deprived state, and/or driving at night. The 26 primary references, in order of first author, are listed on page 93. Where available there are abstracts shown for each study. In many cases, several publications pertained to the same study. In total, there were 13 distinct studies. These are shown in the following subsection and are reviewed in the Article Summaries, using the format prescribed by FMCSA.

Distinct Studies

1. **Effects of long hours on critical incidents; Survey of truck drivers and companies in an unregulated state (Australia)**

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

2. **Exceeding HOS (New Zealand) and performance; Survey of truck drivers on current level of fatigue, driving and sleep in previous 48 hr; Measures of vehicle control and reaction time in simulator**

   Baas, P.H., Charlton, S., and Bastin, G. (2000). "Survey of New Zealand truck driver fatigue and fitness for duty." 4th International Conference on Fatigue and Transportation, Fremantle, Western Australia.

   Charlton, S.G. and Baas, P.H. "Fatigue and fitness for duty of New Zealand truck drivers." (1998). Road Safety Research, Policing, Education Conference. Wellington, New Zealand. Vol. 2. 214–9.

3. **Effects of sleep schedules on performance; Sleep and Lab study; Actigraphic assessment of sleep and sleep log data for long- and short-haul drivers over an extended period—during on and off duty periods; Performance on psychomotor tasks (e.g., Driving simulator, PVT, Walter Reed Performance Assessment Battery)**

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

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

4. **Effects of sleeper berth usage on driver fatigue; Driver performance information: steering, lane departure, braking; Subjective alertness ratings**

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

   Federal Motor Carrier Safety Administration. "Impact of sleeper berth usage on driver fatigue." (2002). Report Number: FMCSA-RT-02-050.

5. **Team vs. single long-haul driving; Performance and subjective levels of fatigue over 4,500 Km trip (Australia)**

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

6. **Time of day effects on performance (e.g., lane position, speed, etc.) in simulated driving task; effect of naps on performance**

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

7. **Driver sleepiness-related problems; Driver's health status; Survey of professional drivers on frequency of prolonged driving and near-miss situations**

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

8. **Impact of local short-haul operations on driver fatigue; Measures to assess fatigue, inattention and drowsiness; Analysis of critical incidents**

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

   FMCSA Tech Brief, 2001 (FMCSA-MCRT-01-006). "Impact of local/short-haul operations on driver fatigue: Field study."

9. **Comparison of fatigue (objective and subjective measures) and driving performance for single versus team drivers on-the-road**

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

10. **Antecedents of fatigue, close calls and crashes among CMV drivers; Survey of CMV drivers**

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

11. **Effects of schedule, loading and recovery on alertness and performance (e.g., lane position, speed maintenance, PVT) of CMV drivers driving on a simulator**

    O'Neill, T.R., Krueger, G.P., Van Hemel, S.B., and McGowan, A.L. (1999). "Effects of operating practices on commercial driver alertness." Rep. No.

FHWA-MC-99-140, Office of Motor Carrier and Highway Safety, Federal Highway Administration, Washington, D.C.

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

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

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

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

12. Effect of sleep deprivation on performance; Effect of four work-rest schedules (2 complying with HOS regulations; two alternative schedules) in simulator and on-road (Australia)

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

Williamson, A., Feyer, A., and Friswell, R. (1996). "The impact of work practices on fatigue in long distance truck drivers." *Accident Analysis & Prevention,* Vol. 28, No. 6, 709–719.

13. Effects of work-rest schedule on performance, critical incidents. Naps and recovery (U.S.-Canada Study)

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

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

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

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

Secondary Sources

The selection criteria for the secondary references were that they were relevant to issues of fatigue and truck driving but not necessarily involving actual driving by truck drivers or typical truck driver schedules. These are listed on page 99.

ARTICLE SUMMARIES

Reviewers: Dianne Davis, Alison Smiley

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

Abstract: This paper summarizes the results of a survey conducted with 1,249 truck drivers and 84 management representatives of transport companies. Data were collected in an Australian state which, at the time of the survey, did not restrict driving hours for heavy haulage drivers. Regulations were being discussed to limit driving to 14 hr in any 24-hr period and restricting driving hours over the week to 72 hr. The aim of the study was to obtain information about hours of work and sleep from drivers operating in a state without restrictions on driving hours (i.e., unregulated drivers). Drivers were asked to provide details about their driving and non-driving work schedules and the amount of sleep they had obtained in the past week. They were also asked to give an hour-by-hour record of activities, feelings of fatigue, and encounters with dangerous events over the 24 hr prior to the interview. Drivers and company representatives were interviewed about their perceptions about fatigue (e.g., factors perceived to be related to fatigue, causes, management) and whether they felt fatigue was problematic for truck drivers. A definition of fatigue was not provided. The authors concluded the paper by comparing their data on unregulated drivers' perceptions about fatigue to those reported by Williamson et al. (1992) for mainly regulated drivers.

Methodology: Survey conducted with 1,249 truck drivers and 84 management representatives of transport companies.

Scope of Work: Survey conducted at road houses in Australia with truck drivers. A second questionnaire was used with management representatives of transport companies in the same state. No literature review was reported.

Sample Size: 1,249 truck drivers; 84 management representatives

Industry Sector: Heavy road transport industry

Major Limitations: Study relies on driver's memories of their sleep and work activities as well as fatigue levels rather than objective measures. As a definition for fatigue was not provided for drivers or company representatives it is difficult to know how participants were interpreting this concept. In addition, comparisons with other studies must be viewed cautiously, since questions and response options were not identical.

Findings

1. In a 24-hr period, approximately 38% of drivers exceeded 14 hr of driving and 51% exceeded 14 hr of driving plus other non-driving work
2. Approximately 17% of unregulated drivers exceeded 72 hr of driving in the week. When non-driving work was added, 30% worked in excess of 72 hr.
3. Approximately 12% of drivers reported less than 4 hr of sleep on 1 or more working days in the week preceding the interview. These drivers were likely to be operating their vehicles while having a significant sleep debt.
4. Approximately 20% of drivers who reported having less than 6 hr of sleep before starting their current journey reported 40% of the hazardous events.
5. Many drivers and company representatives reported fatigue to be a problem for other drivers but considered themselves or their companies' drivers to be relatively unaffected by fatigue.
6. Nearly 70% of company representatives thought that long hours of driving were a main contributor of fatigue, while only 40% of drivers named long hours. About half the company representatives thought lack of sleep contributed to fatigue while about one-third

of drivers thought so. Companies also identified inexperience as a cause of fatigue more often than did drivers. In contrast, more drivers blamed both loading the truck and delays in loading for their fatigue while fewer company representatives identified these two causes.

7. The authors concluded the paper by comparing their data on unregulated drivers' perceptions about fatigue with those reported by Williamson et al. (1992) for mainly regulated drivers. The results suggest that unregulated drivers perceive fatigue to be a problem for themselves less frequently than regulated drivers (10% versus 28 to 35%). Similarly, fewer unregulated drivers considered fatigue to be a general industry problem than did regulated drivers (39% versus 78%). These differences in frequency ratings may be due to differences in the attention paid to fatigue as a safety problem in regulated and unregulated states. In addition, it is possible that regulated drivers experience more fatigue because of long driving hours and less discretion to rest, than do the unregulated drivers. However, the authors caution that, in comparing the two studies, one must bear in mind that each asked different questions of drivers' perceptions of fatigue and provided different response options.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 476, *"Twelve percent of drivers who reported having had a crash in the previous 9 months identified fatigue as a contributing factor."*

p. 476, ". . . *drivers appear to be over confident about their own resilience to fatigue even though they recognize that others are at risk of experiencing fatigue while driving."*

p. 473, "*Five percent of the unregulated drivers reported having experienced a hazardous, fatigue related event, such as nodding off, on their current journey."*

p. 473, ". . . *20% of drivers who reported having had less than 6 hours sleep reported 40% of the hazardous events."*

Driver Duration

p. 472, ". . . *38% of drivers exceeded or would exceed 14 hours of driving in the 24 hour period. When other non-driving work was taken into account, the proportion exceeding 14 hours of work per 24 hour period increased by about 13%.*"

p. 472, ". . . *17.5% of unregulated drivers exceeded 72 hours of driving in the week. When non-driving work is added, 30% worked in excess of 72 hours.*"

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewer's Notes:

This paper was one of several in a special issue of the journal *Accident Analysis & Prevention* that focused on fatigue and transport.

Reviewers: Dianne Davis, Alison Smiley

Title: Baas, P.H., Charlton, S., and Bastin, G. "Survey of New Zealand truck driver fatigue and fitness for duty." (2000). 4th International Conference on Fatigue and Transportation, Fremantle, Western Australia.

Abstract: This paper summarizes the results of a survey of truck driver fatigue in New Zealand. Interviews and performance tests were collected from truck drivers at various locations throughout the North Island of New Zealand throughout the day and night. In an analysis of the first 100 drivers, the researchers found that a sizable number of drivers exceeded the allowable driving hours. They also found high levels of fatigue and sleepiness and differences between line-haul and local delivery drivers.

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

Scope of Work: Interviews and simulator-based performance tests conducted at depots, wharves, markets, and other locations throughout the North Island of New Zealand throughout the day and night.

Sample Size: 600 truck drivers ranging from 19 to 59 years of age (average age = 36; average years of experience = 13.76 years)

Industry Sector: Truck drivers (74% company employee drivers, 20% subcontractors, 4% working for owner/drivers, 2% independent owner/drivers)

Major Limitations: Study summarizes only initial results of the first 100 drivers. Selected performance indices are not necessarily valid predictors of crash risk.

Findings

1. "The drivers' typical workday length ranged from 6 to 15 hr with an average across all drivers of 11.89 h and a S.D. of 1.683."
2. "The average number of days driving per week ranged from 3 (relief and part-time drivers) to 7, with an average of 5.35 days, standard deviation of 0.557 days."
3. Drivers typically rated fatigue to be a problem for other drivers more often than for themselves.
4. A much lower percentage of drivers rated fatigue as "never" being a problem for them than did drivers in Hartley et al.'s study (13% as opposed to 35.5% in Hartley et al.).
5. Large numbers of drivers did not comply with the HOS regulations.

6. Drivers had an average of just 1.5 meals per day (0.5 of a meal was defined as a light snack, usually while driving).
7. The average Epworth Sleepiness Score of 7.53 (S.D. of 4.47) was substantially higher than the average score of 5.7 for truck drivers and 6.2 for automobile drivers reported in previous research (Maycock 1995).
8. Of all drivers, 91% passed all five performance criteria for the performance test on the simulator. "Of the 9% of drivers displaying driving performance below the criterion level, eight drivers failed the first performance criterion, a linear combination of measures predominantly associated with curvature error variability."
9. "Of the drivers' activity and demographic measures, two were found to be particularly reliable predictors of simulator task performance: average distance driven per shift and driver age, $F(2, 98) = 8.42$, $P < 0.01$. Drivers with an average daily route of fewer than 250 km and drivers 37 years and older were much more likely to fail the performance test." The authors noted that at this stage it was unclear "how to interpret the route length and age effects in the TOPS results."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 188, Baas, *"The drivers typically rated fatigue to be a problem for other drivers (21% rating it always or often a problem) more often than for themselves (8% rating it a problem always or often)."*

p. 476, *"The average Epworth Sleepiness Score of 7.53 (S.D. of 4.47) in our sample is substantially higher than the average score of 5.7 for truck drivers and 6.2 for automobile drivers reported in previous research (Maycock 1995)."*

Driver Duration

p. 188, Baas, "*The drivers' typical workday length ranged from 6 to 15 hr with an average across all drivers of 11.89 h and a S.D. of 1.683."*

p. 188, Baas, "*The average number of days driving per week ranged from 3 (relief and part-time drivers) to 7, with an average of 5.35 days, standard deviation of 0.557 days."*

p. 188, Baas, *"The results of the activity survey provide clear evidence that large numbers of drivers are not complying with the hours of service regulations" (i.e., no more than 11 hours on duty? Driving?, with at least 9 consecutive hours of rest between driving shifts. " Thirty-three percent of drivers admitted to driving longer than 11 h in 24, and only 69% of drivers reported at least 9 consecutive hours of rest (9 hours sleeping plus hours relaxing) between driving shifts."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

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

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

N.B. In the summary of this study, not all direct quotes are indicated as such.

Abstract: A study was conducted to gather and analyze data on CMV driver rest and recovery cycles, effects of partial sleep deprivation, and prediction of subsequent performance. The project was composed of two studies. The first study was a field study using wrist actigraphy to determine sleep duration and timing in long- versus short-haul CMV drivers over 20 consecutive days. The second study was a sleep dose/response (SDR) laboratory study on CMV drivers to determine the effects of 3, 5, 7 and 9 hr time in bed on performance (including simulated driving) over 7 consecutive days. The findings from the laboratory study were used to "optimize the parameters of the Walter Reed Sleep Performance model (SPM)—a mathematical algorithm to predict performance based on prior sleep and circadian rhythm.

Methodology: *Field Study*

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

Laboratory Study

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

Scope of Work: Historical and methodological overview of sleep and performance, description of sleep/performance model, field study using actigraphs, laboratory study of effect of sleep restriction on performance.

Sample Size: Field Study: 50 long- and short-haul CMV drivers ages 21 to 65; Lab Study: 66 CMV drivers (16 females, media age = 43; 50 males, mean age = 37)

Industry Sector: Long- and short-haul driving

Major Limitations:

Field Study

- Actigraphy does not allow scoring of sleep stages, which may be differentially restorative.
- The reliability of actigraphy in a moving motor vehicle (e.g., when a driver is sleeping in a sleeper berth of a moving vehicle) is currently unknown.
- The reliability of subjective reports (e.g., subject logs) is typically low.
- Two potential sources of error were uncovered during this study:
  - Time zones: Some drivers' company work sites were in a time zone different from the time zone in which the driver resided.
  - Shifts to and from Daylight Saving Time (DST): Several drivers participated during shifts to or from DST. These shifts were reflected in the RODS (Driver's Daily Log Sheets), but not in the actigraph data. These times had to be identified and the actigraph data adjusted to match the RODS.
- The strength of this study is that all periods of sleep, not just those taken off-duty, were recorded for a large group of CMV drivers over an extended period of time.

Laboratory Study

- Study only looked at daytime driving.
- Recovery sleep was restricted to 8 hr.
- The trade-off for using a wide variety of measures was that the number of daily administrations for each particular measure was restricted—precluding evaluation of circadian rhythms in this study.
- Subjects were heterogeneous with respect to age, which may have contributed to error variance in performance measures.

Findings

Field Study

1. Both long- and short-haul drivers averaged approximately 7.5 hr of sleep per night, which is within normal limits for adults. "However, the short-haul drivers tended to consolidate their daily sleep into a single, off-duty period, whereas long-haul drivers obtained approximately half of their daily sleep total as daytime naps and/or during sleeper-berth time."
2. As long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleep-berth time), it appears that they spend a significant portion of the work shift in a state of partial sleep deprivation, until the opportunity to obtain on-duty recovery sleep presents itself.
3. There was no off-duty duration that guaranteed adequate sleep for the long- or short-haul drivers. As drivers likely use a substantial portion of their off-duty time to attend to personal business, off-duty time must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off-duty periods.
4. The bulk of the first (main) daily sleep bouts for short-haul drivers were initiated between 2000 and 0200. Sleep bouts initiated at these times lasted longer (i.e., clustered between 6 and 10 hr) than sleep bouts initiated at other times of day. Several of the sleep bouts initiated between these times lasted longer than 12 hr.
5. Similar to the short-haul drivers, the majority of long-haul drivers' first sleep bouts were initiated between 2200 and 0359. However, long-haul drivers initiated their first sleep bouts more frequently during 0000 and 0359. The duration of long-haul drivers' first sleep bouts clustered between 6 and 10 hr in duration. Sleep bouts exceeding 10 hr in duration

were uncommon and none exceeded 12 hr. Some sleep bouts were initiated in the early and late afternoon hours (1200 to 1959) and, unlike short-haul drivers, almost half of the first sleep bouts initiated during this time frame were longer than 4 hr in duration.

6. There were large day-to-day variations in total sleep time for drivers in both groups. Sleep times varied for some long- and short-haul drivers by up to 11.2 hr across the 20 study days for the long and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules. Some showed a pattern that suggested chronic sleep restriction with intermittent bouts of extended recovery sleep. The authors felt that this suggested that although work-rest schedules could be devised to help minimize CMV driver sleep debt, optimal enhancement of driver alertness and performance would require additional and imaginative approaches.

Laboratory Study

1. On average, subjects slept 2.9, 4.7, 6.3, and 7.9 hr for the 3-, 5-, 7-, and 9-hr time in bed conditions respectively, and displayed dose-dependent performance impairment related to partial sleep loss. (As can be deduced from these sleep times, as sleep restriction was more pronounced, sleep latency periods declined, resulting in greater sleep efficiency or proportionally more sleep in the available period.)
2. Performance in the 3-hr sleep group typically declined below baseline within 2 to 3 days of sleep restriction.
3. Performance in the 5-hr sleep group was consistently lower than performance in the 7- and 9-hr sleep groups.
4. Performance in the 7- and 9-hr sleep groups was often indistinguishable and improved throughout the study. However, the authors did note that "even a relatively small reduction in average nighttime sleep duration (i.e., 6.3 hr of sleep—the average amount of sleep obtained by the 7-hr group) resulted in measurably poorer performance, for example, on the PVT. This decrement was maintained across the entire consecutive days of sleep restriction.
5. Virtually no negative effects on performance were seen in the 9-hr sleep group.
6. Sleep restriction effects were consistent. The degree to which "sleep restriction impaired performance was measure-specific." "Across tasks, speed and throughput were consistently affected." "In general, performance for the 3- and 5-hour sleep groups was below that of the 7- and 9-hour sleep groups." "Thus, restricting sleep resulted in dose-dependent performance impairment."
7. All cognitive tasks were sensitive to differential sleep restriction.
8. The PVT was the most sensitive measure. (It was also the performance measure which was the most resistant to changes in performance due to learning, an important issue when effects over many days are being examined.) Even the 7-hr group with 6.3 hr of sleep showed decreased performance using this measure across the 7 days.
9. The majority of driving performance measures (e.g., increased lane-tracking variability increased driving speed, increased speed variability, and increased running-off-road accidents) also showed dose-dependent and/or cumulative sleep restriction effects.
10. Following chronic sleep restriction, the first 8 hr in bed (6.5 hr of sleep) was insufficient for restoration of performance on the PVT task.
11. During the 4-day recovery phase (8 hr in bed each night), 5- and 7-hr sleep groups showed minimal or no recovery, remaining consistently below the 9-hr sleep group and below their own baseline levels for the PVT.
12. The 3-hr sleep group showed some recovery for the PVT on the first day and more on subsequent days but also remained well below their own baseline and below the performance of the other groups.
13. Subjects' recovery to baseline or near baseline levels of performance on the PVT often required a second or third night of recovery sleep.

14. These data suggest that after sleep debt has occurred (3, 5, 7 hr time in bed) a single bout of 8 hr of night sleep leads to recovery but not full recovery. While further sleep is required for full recovery, the number of subsequent sleep periods to reach full recovery is unknown. For the 3-hr group, the data suggests that even 3 nights of normal sleep (8 hr spent in bed on each night) is not sufficient to restore performance to baseline levels (depending on the task). This suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration (i.e., more than 8 hr of normal-duration sleep). This is a unique finding and requires replication.
15. In contrast to the findings concerning PVT performance, the accident rate went back to baseline after 1 recovery day for all groups. In addition, lane position variability was near, but not quite back to baseline for all but the 9-hr group. On recovery days, lane position variability was slightly worse for the 9-hr group who, after being allowed 9 hr in bed each night during the work period, were restricted to 8 hr of sleep.
16. None of the physiological health measures (heart rate, blood pressure) evaluated in this study were sensitive to sleep restriction.
17. "Overall highest HR (collapsed across day and time of day) was seen in the 3-hr group (mean BPM = 79.74) and 7-hr sleep group (mean BPM = 78.64), while lowest HR was seen in the 9-hr sleep group (mean BPM = 70.46) and 5-hour sleep group (mean BPM = 75.48; group main effect, $p < 0.05$)."
18. "Across study days (collapsed across sleep group and time of day), highest HRs occurred across the last four days . . . while the lowest HR was observed on day E2."
19. "Within days (collapsed across day and sleep group), the highest HR occurred at 1930 hours (mean BPM –79.87), whereas the lowest HR occurred at 1630 hours (mean BPM –72.60; time-of-day main effect, $p < 0.05$)."
20. Systolic blood pressure did not differ among sleep groups, nor did sleep group interact with day or time of day.
21. The highest systolic blood pressure (SBP) was found on day E4, the fourth experimental day, while the lowest SBP occurred on Day R2, the second recovery day. With respect to time of day, the highest SBP occurred at 1320, while the lowest SBP occurred at 0715.
22. "Diastolic pressure did not vary as a function of sleep group or day, nor did these factors interact (main effects and interactions, ns)."
23. "Diastolic pressure varied across the day (time-of-day main effect, $p < 0.05$)—the highest DBP values occurred at 0715 hours, and the lowest DBP occurred at 1025 hours. DBP values at 1320, 1625, and 1920 were intermediate between 0715 and 1025 hours and similar among each other."

Findings Directly Related to HOS (include page references):

Driver Sleep

p. ES-5, Field Study: ". . . both long- and short-haul drivers averaged approximately 7.5 hours of sleep per night, which is within normal limits for adults."

p. ES-5, Field Study: "*Time off-duty was positively correlated with total sleep time for both groups, but the short-haul drivers were more likely to consolidate their daily sleep into a single, work-shift sleep period.*"

p. ES-5, Field Study: "*Long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleeper-berth time), which suggests that they spend a significant portion of the work shift in a state of partial sleep deprivation—i.e., until the opportunity to obtain on-duty recovery sleep presents itself.*"

p. ES-5, Field Study: ". . . *there was no off-duty duration that guaranteed adequate sleep. . . .*"

p. ES-5, Field Study: ". . . *large day-to-day variations in total sleep time were evident for drivers in both groups. . . .*"

Driver Performance

p. ES-8, Lab Study, ". . . even a relatively small reduction in average nighttime sleep duration (i.e., 6.28 hours of sleep—the average amount of sleep obtained by the 7-hour group) resulted in measurably decremented performance (e.g., on the PVT). This decrement was maintained across the entire 7 consecutive days of sleep restriction, suggesting that there was no compensatory or adaptive response to even this mild degree of sleep loss."

p. ES-8, Lab Study, ". . . *the extant level of daytime alertness and performance capacity is a function not only of an individual's circadian rhythm, time since the last sleep period, and duration of the last sleep period, but is also a function of his/her sleep history, extending back for at least several days.*"

Driver Recovery

p. ES-8, Lab Study, ". . . *following more severe sleep restriction (e.g., the 3-hr group), recovery of performance was not complete after 3 consecutive nights of recovery sleep . . . this suggests that full recovery from substantial sleep debt requires recovery sleep of extended duration.*

Driver Health

p. 2-88, Lab Study, *"These results do not support the notion that physiological measures can serve as indices of subtle changes in cognitive performance capacity following sleep loss . . . To date, there is only limited evidence that sleep restriction, or sleep deprivation, affects physiological systems under involuntary control. In fact, none of the physiological health measures evaluated in this study (heart rate, respiration, and blood pressure) were sensitive to sleep restriction. These results also are consistent with the view that sleep deprivation mainly impairs higher-order cognitive performance."*

Reviewers: Dianne Davis, Alison Smiley

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

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

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

N.B. All quotes are from FMCSA summary.

Abstract: This report documents research that was conducted on sleeper-berth usage. In addition to focus groups with long-haul operators, a field study was conducted on sleeper-berth usage for single and team drivers. The report outlines a number of factors, discovered in the focus groups, which are important to successful sleeper-berth usage for single and team drivers. Based on the results of the focus group and an accompanying literature review the researchers designed an on-road study with 56 drivers (47 male, 9 female; mean age = 42.6) constituting 13 teams and 30 single drivers to assess the effects of sleeper-berth usage on sleep, driver error, and critical incidents.

Methodology: Focus Groups: Ten focus groups were conducted in 8 cities, across 7 states. Field Study: Long-haul truck drivers operated heavy trucks for a minimum of 6 continuous days, with the typical run being 7 to 10 working days, on their regularly assigned route. Data collection systems were installed on the tractors used by the drivers to collect sleeper-berth environmental data, driving performance information, video of the driver's face, and subjective alertness ratings and data from the Nightcap sleep system. Data (i.e., computer and video) were collected before and during critical incidents such as lane and steering deviations.

Scope of Work: Based on the findings of the focus groups and a literature review, a field study protocol was developed to assess the impact of sleeper berth usage. The field study was designed to determine relationships between sleep quality, driver alertness, and driving performance.

Sample Size: Focus Groups: 74 participants (27 to 70 years of age).

Field Study: 56 drivers participated in the field study (30 single drivers and 13 teams of drivers; 7 females, 49 males; mean age = 42.6).

Industry Sector: Long-haul operators

Major Limitations: n/a

Findings *Focus Groups*

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

Field Study: Team Driving vs. Single Driving

2. Single drivers were involved in significantly more critical incidences than team drivers. They were involved in "four times the instances of "very/extremely drowsy" observer ratings than were team drivers, and were more likely to push themselves to drive on occasions when they were very tired."
3. More than one-half of the most severe of the critical incidents were caused by 4 of the 30 single drivers. In contrast, team drivers were generally very successful at avoiding circumstances of extreme drowsiness, drove much less aggressively, and made fewer errors than single drivers.
4. The main effect for segment of day was significant ($p < 0.05$). Team drivers tended to exhibit critical incidents associated with extreme fatigue during the morning and night hours (morning: 0400 to 1159; afternoon: 1200 to 1759; night: 2200 to 0359). Single drivers "tended to show fewer extreme fatigue-related critical incidents during the morning hours, with gradually more critical incidents being attributed to the very drowsy categories during the evening and nighttime hours." The authors note that single drivers "were exhibiting signs of extreme fatigue during all hours of the day while team drivers only showed signs of fatigue during the nighttime and morning hours."
5. Overall, team drivers were able to better manage their fatigue and critical incident involvement than were single drivers. This may be because team drivers are more likely to effectively trade-off driving duties with their partner before to becoming extremely fatigued. It is also possible that in effect, drivers undergo a natural "screening" process. Focus group participants noted that team drivers must be trustworthy with regard to their driving ability and be considerate of their resting partner.

Field Study: Quality of Sleep

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

Field Study: Hours of Service

7. "In terms of hours of service violations, based on a report by Wylie et al. (1996), there were relatively few instances (about 2.2%) of "extreme drowsiness," with most of these instances being experienced by single drivers, again with a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive." There were relatively few instances of "extreme drowsiness" (2.2%), with most of these instances being experienced by single drivers, with a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive."
8. The authors note that it "appears that the combination of long driving times and multiple days provides the greatest concern, with several results pointing to the presence of cumulative fatigue." As a result they believe that the length of shifts in the later stages of a trip must also be considered. However, the authors point out that "critical incidents and/or driver errors did not increase directly with the hours beyond the regulation," and that "there was a substantial decrease in the rate of critical incidents during some of the more extreme violations." However, they do caution that this should not be interpreted to mean that HOS should be expanded due to the following two reasons: "First, it may be possible that the drivers were making a point to drive more carefully and cautiously because they were operating outside of the regulation and did not want to get stopped by law enforcement officials. Alternatively, they may have only risked driving outside of the regulations because they felt alert and knew that they could continue to drive safely."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 3 Tech Report FMCSA-RT-02-070, ". . . *team drivers were generally very successful at avoiding circumstances of extreme drowsiness. Conversely, single drivers were greatly affected by drowsiness, which in turn, compromised their ability to safely operate their vehicles."*

p. 3 Tech Report FMCSA-RT-02-070, ". . . *team drivers appeared to drive much less aggressively, make fewer errors, and rely effectively on their relief drivers to avoid instances of extreme drowsiness while driving."*

p. 4 Tech Report FMCSA-RT-07-070, *". . . single drivers in this study had many more critical incidents at all levels of severity as compared to team drivers. Single drivers were involved in four times the instances of "very/extremely drowsy" observer ratings than were team drivers, and were more likely to push themselves to drive on occasions when they were very tired. In fact, in looking at only the most severe of the critical incidents, more than one-half of the incidents were actually caused by four single drivers."*

Driver Duration

p. 4 Tech Report FMCSA-RT-07-070, *"In terms of hours-of-service violations, based on a report by Wylie et al. (1996), there were relatively few instances (about 2.2%) of "extreme drowsiness," with most of these instances being experienced by single drivers, again with a high rate of the occurrence of this level of fatigue on the second or third shift after the first day of a multi-day drive. Thus it appears that the combination of long driving times and multiple days provides the greatest concern, with several results pointing to the presence of cumulative fatigue. This means that the length of shifts in the later stages of a trip must also be carefully considered."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

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

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

Methodology: "A between groups design was used for this study, in which each participant only drove one evaluated trip using his regular operation—either two-up or single." Drivers were asked to drive a 4- to 5-day round trip of approximately 4,500 km in Western Australia. At the time of the study, the state of Western Australia did not have enforced driving hours regulations. Twenty-two of the 37 participants regularly worked two-up operations on the selected route and 15 regularly worked as single drivers. A variety of measures were used to assess drivers' fatigue and its effects such as heart activity, speed and steering wheel angles, auditory reaction time tasks, cognitive tests, and subjective measures of fatigue. Prior to starting their trip, participants were also asked to complete questionnaires about their general state of physical health, their lifestyle, and their pattern of work-rest in the week preceding the study.

Scope of Work: Field study of single versus team drivers conducted in Western Australia.

Sample Size: 37 male professional long-distance drivers (average age = 37; average of 13 to 15 years of commercial driving experience)

Industry Sector: Professional long-distance drivers

Major Limitations: The state of fatigue of the two groups being compared, two-up and single drivers, was not equivalent at the start of the study.

Findings

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

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 550, "Overall, the heart rate measures confirmed earlier findings that single drivers were more alert than two-up drivers at the start of the trip."

p. 552, "Two-up drivers reported and showed evidence of greater fatigue than single drivers before the trip started and appeared to be more fatigued overall for most of the trip."

p. 552, "Over the homeward leg of the trip, two-up drivers reported no change in the level of fatigue, with fatigue having peaked at mid trip. For single drivers, in contrast, fatigue peaked at the end of the homeward leg, despite considerable recovery at mid trip."

p. 552, "Overnight stationary rest for two-up drivers at mid trip, was associated with dramatic reductions in fatigue levels after the break, and allowed these drivers to finish the trip with the lowest levels of fatigue of any group, including single drivers."

p. 552 "Two-up drivers who had no stationary rest, but had the shortest trip duration of any group, showed an overall increase in alertness over the homeward journey, finishing the trip at roughly pre trip fatigue levels."

Driver Duration

p. 553, "*Working hours regulations for long distance drivers are primarily based on limitations to periods of driving and rest within a trip, largely in isolation from overall scheduling patterns. In contrast, the current findings strongly suggest that effective management of fatigue involves considerations of the whole pattern and timing of work and rest . . ."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

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

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

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

Scope of Work: Simulator study

Sample Size: Nine professional drivers (mean age: 42 years, range 28 to 55 years; mean professional experience: 17 years; mean experience of night work: 8 years).

Industry Sector: Professional truck drivers

Major Limitations: Relatively short task (continuous driving for only 30 min at a time), with a maximum of 1.5 hr of driving, on a simulator.

Findings

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

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 14, "Sleepiness ratings: These were significantly (F = 20.6; P = 0.0001) higher during the night conditions compared to the day (DAYDRIVE 4.3 < NIGHTDRIVE 6.0; NIGHTCAP 5.7; NIGHTREST 5.5)."

p. 14, "The level of sleepiness increased significantly (ANOVA) across the three 30-min periods (F1,8 = 27.8; P = 0.0008; changes from before period 'a' to after period 'c'" DAYDRIVE 3.3–5.6; NIGHTDRIVE 5.1–7.2; NIGHTNAP 4.0–7.1; NIGHTREST 4.4–6.7).

p. 473, "Mean percentage of time with sleepiness differed significantly between the day and night driving conditions (F = 4.8; P = 0.0453; DAYDRIVE 29.6 < NIGHTDRIVE 43.6; NIGHTNAP 33.2; NIGHTREST 41.9)."

Driver Skill

p. 13, ". . . *when contrasting only the last 30-min periods the mean speed was significantly higher during the day compared to the three night conditions."*

p. 13, ". . . *speed variation during period 'c' was significantly lower during the day drive compared to the three night conditions* ."

p. 13, ". . . *for period 'c' the lane position varied significantly less during the day* ."

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Hakkanen, H. and Summala, H. (2002). "Driver sleepiness-related problems, health status, and prolonged driving among professional heavy-vehicle drivers." *Transportation Human Factors*, 2(2), 151–171.

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

Methodology: A questionnaire was sent to "2,000 randomly chosen members of a nonpolitical organization promoting truck drivers' interests (16,508 members in all)." A total of 567 usable questionnaires were returned. The questionnaire contained questions on individual characteristics, their preceding 3 months' work, possible sleepiness-related problems at work and their opinions about maximum permitted driving times. In addition, they were also given parts of the Basic Nordic Sleep Questionnaire and the Epworth Sleepiness Scale to estimate the "prevalence of suspected sleep apnea syndrome and to collect data of driver's sleep history." Drivers were also asked questions about their self-perceived general health status and the occurrence of any chronic illnesses.

Scope of Work: Questionnaire distributed to 2,000 professional drivers in Finland.

Sample Size: 567 drivers (long-haul drivers = 44%; short-haul drivers = 25%; drivers transporting dangerous goods = 16%; drivers transporting wood = 8%; bus drivers = 7%)

Industry Sector: Professional drivers

Major Limitations: Study relies on driver's memories of their sleep and work activities as well as fatigue levels rather than objective measures. Screen for sleep apnea only took place through questionnaires.

Findings

1. "The results of the study indicated that approximately one-third of all the drivers drive generally more than 10 hr, which violates the EC regulation."
2. "More than 70% of the drivers felt that the maximum permitted driving hours should be at least 11 hr per a 24-hr period."
3. Nineteen percent reported having dozed off at least twice while driving, and 8% reported a near-miss situation due to dozing off during the past 3 months.
4. "Sleepiness-related problems while driving appeared across all driver groups (i.e., long haul, short haul, bus drivers, drivers transporting dangerous goods, drivers transporting wood), including drivers transporting dangerous goods and bus drivers, and were strongly related to prolonged driving, sleep deficit and drivers' health status." The effects of the latter factors were interactive and cumulative: Frequent sleepiness-related problems occurred in more than one half (52.3%) of the "drivers with the combination of prolonged driving, sleep deficit, and lowered self-perceived health."
5. The 10% of drivers who were suspected to have sleep apnea syndrome (note: screening through questionnaires only) reported having experienced significantly more frequent sleepiness-related problems while driving although they did not report a significant increase in the frequency of sleepiness-related accidents.

6. Thirty-one percent of the drivers perceived their general health status to be no more than satisfactory.
7. Drivers who reported their health status to be no more than satisfactory were ”significantly older, reported driving for longer hours, had experienced more frequent difficulties in remaining alert, dozing off, and following near-miss situations while driving, as well as accidents at work due to dozing off.”
8. A significantly higher percentage of those drivers who perceived their health as satisfactory as compared with those rating it at least good, reported driving generally more than 10 hr (12% vs. 5%).
9. “A significantly higher proportion of drivers with no more than satisfactory health also had more than a 1-hr average sleep deficit, compared to drivers with self-perceived good or excellent health (29% vs. 13%).”
10. Twenty-five percent reported having detected a chronic illness during the past 3 years. Drivers with an illness were “significantly older, had been driving for longer hours, reported more frequent difficulties in remaining alert and dozing off while driving.” A significantly higher percentage of these drivers reported driving generally more than 10 hr than drivers with no illness (11% vs. 6%). In addition, “of the drivers with an illness 23% had more than a 1-hr average sleep deficit compared to 17% of drivers with no illness.”
11. According to the authors, the connection between a chronic illness and sleepiness-related problems while driving was somewhat mixed. While “the univariate comparison between those with an illness and others suggested a marked difference in sleepiness-related problems,” the “logistic regression analysis showed that when other relevant factors were controlled (e.g., age, driving time) the effect of a chronic illness was no more significant whereas perceived health status better explained sleepiness-related problems while driving.” They suggested that this result might be partly due to the fact that the discovered illnesses were rather heterogeneous. “Further concern is raised by the results that nearly one fourth of the drivers with an illness had sleep deficit. In addition, compared to the drivers with no illness, prolonged driving was more common among drivers with a chronic illness.”
12. Increased odds of having more frequent difficulties in remaining alert if the driver self-perceived as having no more than satisfactory health.
13. The authors conclude that the results give unreserved support for regulating driving hours and increase concern of the connection between professional drivers’ health status and sleepiness-related problems while driving.
14. Drivers were more apt to have frequent difficulties remaining alert if they had been driving a night or irregular shift, or had been driving more than 17 hr.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 169, *“The results indicate that to a certain degree sleepiness-related problems while driving seem to be associated with the interactive effect of prolonged driving, sleep deficit, and subjective health status. After all, frequent sleepiness-related problems were substantially more common among drivers with the combination of no more than a satisfactory health, prolonged driving, as well as sleep deficit. Notably, frequent difficulties in remaining alert and dozing off had occurred in more than one half of these drivers whereas in only approximately 10% of those drivers with a driving time of at most 10 hr, no sleep deficit, and at least a good health. Therefore, restricting driving hours may in fact help to improve occupational health as well as traffic safety.”*

p. 169, *“. . . the analysis indicated that prolonged driving (in terms of driving more than the permitted driving hours set by the EC regulation) is indeed associated to sleepiness-related problems while driving whether they be difficulties in remaining alert, dozing off, or near-miss situations and that difficulties in remaining alert are associated with driving a night or irregular shift.”*

p. 162, *". . . when all the relevant factors were controlled, shift type and driving time were the only work-related variables that significantly predicted more frequent difficulties in remaining alert (p < .05 and p < .05, respectively). The odds of having experienced more frequent difficulties increased by a factor of 1.85 if the driver had been driving a night or irregular shift and by 3.57 if the driver had been driving more than 17 hr (compared to fewer than 6 hr driving)."*

Driver Duration

p. 166, *". . . approximately one third of all the drivers drive generally more than 10 hr, which violates the EC regulation."*

p. 166, *"More than 70% of the drivers felt that the maximum permitted driving hours should be at least 11 hr per a 24-hr period."*

Driver Health

p. 169, " *The univariate comparison between those with an illness and others suggested a marked difference in sleepiness-related problems, but the "logistic regression analysis showed that when other relevant factors were controlled (e.g., age, driving time) the effect of a chronic illness was no more significant whereas perceived health status better explained sleepiness-related problems while driving."*

"p. 169 *". . . the analysis indicated that the effect of suspected sleep apnea syndrome on sleepiness-related problems while driving was significant when predicting dozing off."*

p. 169, *". . . an important result of the logistic regression analysis is that of increased odds of having more frequent difficulties in remaining alert if the driver self-perceived as having no more than a satisfactory health."*

Reviewers: Dianne Davis, Alison Smiley

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

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

Methodology: The authors used subjective, objective, and physiological measures to assess fatigue, inattention, and drowsiness. Subjective measures included self-report on levels of stress. Objective measures included the degree of eyelid closure. Physiological measures included indications of sleep quantity and quality as collected by wrist activity monitors. In addition the "black box" data collection equipment installed in the truck collected driver performance associated with "critical incidents," (i.e., near-crash events). Several small video cameras were used to monitor each truck driver and surrounding traffic situation, and sensors collected data from the vehicle's instruments. The authors conducted analyses of videotape of the 3-min interval preceding the start of a critical incident. An incident was defined as a control movement exceeding a threshold based on driver or analyst input. Analysts recorded eye transitions and the proportion of time that the driver's eyes were closed/nearly closed, or off the road, during these 3-min intervals.

Scope of Work: On-road field study where L/SH trucks were instrumented with data collection equipment. As a precursor to this research, the authors had conducted a series of focus groups in which L/SH drivers provided their perspective on safety issues, including fatigue, in their industry. (The results of these discussions are summarized in publication no. FHWA-MCRT-99-002). The authors propose five guidelines aimed at reducing critical incidents that are caused by L/SH drivers.

Sample Size: 42 local and short-haul drivers (mean age = 31); 30 drivers from the beverage company and 12 drivers from the snack food company)

Industry Sector: Local and short-haul truck driving

Major Limitations: Only daytime driving was considered. Amount of last recovery time before starting the study was unknown.

Findings

1. Over the 2-week period, there were 77 incidents (average 1.8 per driver) where the driver was judged to be at fault.
2. Inattention was thought to be involved in 57 critical incidents and fatigue a contributor to 28 critical incidents (i.e., 20.8% of incidents where the L/SH driver was judged to be at fault).
3. The majority of the L/SH driver at fault critical incidents were caused by about one-quarter of the drivers.
4. Ten of the 42 drivers were involved in 86% of the incidents.
5. The younger and less experienced drivers were significantly more likely to be involved in critical incidents and exhibited higher on the job drowsiness.
6. "Drivers tended to be involved in fatigue-related incidents earlier in the workweek. There were no fatigue-related critical incidents after the fourth day of the workweek."
7. The highest frequency of driver-at-fault incidents was between noon and 1:00 p.m. The increase in incidents during these periods may be attributed to increased exposure.

8. During the study, the drivers' mean sleep was 6.43 hr per night (sleep log) and 5.31 hr based on the Actiwatch (developed by Mini Mitter Co., Inc.).
9. Data was divided into two groups where fatigue was apparent or not apparent. "To classify incidents into one of these two groups, threshold values for PERCLOS and OBSERV were set such that fatigued drivers were defined as having PERCLOS greater than or equal to 0/08 or an OBSERV value greater than or equal to 40. If an event did not meet one of these criteria, then the driver was deemed to be 'not fatigued.'" Drivers who showed evidence of fatigue and were involved in fatigue related incidents had less sleep and poorer quality sleep than drivers who did not show signs of fatigue. The drivers from the beverage company typically worked 10 to 11 hr per workday. The snack food drivers worked roughly 12 hr per workday. The majority of drivers worked 5 days per week.
10. The self-reported amount of sleep and quality of sleep for the night before the incident were less when the driver was categorized as being fatigued. Drivers in the fatigue group had 5.33 hr of sleep compared with 6.13 hr in the no-fatigue group.
11. ". . . much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job." The authors concluded that off-duty behavior was the "primary contributing factor in the level of fatigue that was demonstrated during the workday."
12. Drivers in the fatigue group spent more hours driving during the day of the critical incident as compared with drivers in the no-fatigue group.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 155, *"drivers demonstrated, to a statistically significant level, signs of fatigue for a time period immediately preceding incident involvement where the L/SH driver was judged to be at fault.*

p. 155, "*. . . fatigue does appear to be an issue in L/SH trucking operations. Because this was a field study, it is difficult to determine with certainty* ***why*** *fatigue was present."*

p. 155, *". . . based on the results of the multiple analyses that were conducted, it seems apparent that much of the fatigue that the drivers' experienced was brought with them to the job, rather than being caused by the job. That is, poor sleep quantity/quality were prominent for drivers who demonstrated signs of fatigue on the job. Therefore, it is suggested that the off-duty behavior of the drivers was the primary contributing factor in the level of fatigue that was demonstrated during the workday."*

p. 99, *". . . the highest frequency of driver-at-fault incidents was between noon and 1 PM . . . Potential explanations for this finding are that the L/SH drivers may be experiencing drowsiness after eating lunch, or that eating-while-driving, a common observance with the drivers in this study, may have drawn attention away from the driving task."*

Driver Duration

p. 77, "*The total shift time shows that both groups of drivers from the beverage company typically worked 10 to 11 hours per workday, while the snack food drivers worked roughly 12 hours per workday. The majority of drivers worked five days per week."*

p. 112, *". . . drivers in the fatigue group spent more hours driving during the day of the critical incident (M = 4.38) as compared to drivers in the no-fatigue group (M = 3.43).*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

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

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

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

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

Abstract: This project consisted of focus groups, a driver survey, and interviews with CMV drivers focused on the physical requirements (loading/unloading) across the industry. This was followed by a driving simulator study which investigated "fatigue-related decline in driving performance resulting from loading and unloading cargo," "non-duty time (rest and recovery) required to reestablish baseline fitness for duty," and "driver performance under a sustained 14 hours on/10 hours off schedule. Researchers examined driver performance over a 15-day period." Ten male CMV drivers operated a "driving simulator in simulated long-haul runs for a period of 15 days, including occasional loading/unloading sessions and a relatively high frequency of simulated crash-likely events." Performance measures and measures of subjective drowsiness were collected. In addition, participants wore wrist activity monitors to assess the amount of sleep. "The effects of loading and unloading task were mixed. There was an initial improvement in alertness; however, this effect wore off as the day progressed and may have contributed to a decrease in overall performance after 12 to 14 h of duty." "Drivers recovered baseline performance within 24 hours of the end of a driving week and should be fit to resume duty after 36 hours." "A schedule of 14 hours on duty/10 hours off duty for a 5-day week did not appear to produce cumulative fatigue."

Methodology: The experiment used a mixed between-and-within-subjects design that required each of the 10 truck driver subjects to operate a simulator in simulated long-haul runs for a period of 15 days, including occasional loading/unloading sessions and a relatively high frequency of simulated crash-like events (e.g., 8 events in a 12-hr day). The complete test cycle for each driver required 17 days:

- Days 1–2: Simulator and procedural familiarization
- Days 3–7: Week 1 of driving operations
- Days 8–9: Recovery time (58 hr off duty)
- Days 10–14: Week 2 of driving operations
- Days 15–16: Recovery time (58 hr off duty)
- Day 17: Final driving day to verify performance recovery

Drivers were screened for undiagnosed sleep disorders and to verify that the driver began the test period nominally rested by examining the records from a wrist activity monitor for the 48 hr preceding the start of the experiment and the 2-day familiarization period. The authors did not mention that any drivers were disqualified for sleeping disorders.

Drivers were held to a schedule of 14 hr on duty (12 hr driving plus scheduled breaks) followed by 10 hr off duty. The daily driving schedule ran from simulator engine start at 0700 to shutdown at 2100. Breaks were taken on the experimental schedule and not at the subject's discretion (30-min break at 1000, a 45-min lunch break at 1345, and a 30-min break at 1730). During week one of driving, half of the drivers conducted simulated loading/unloading operations for 3 days and no loading/unloading operations in week 2. The remaining drivers did the reverse (i.e., loaded in week 2). On loading days, drivers performed two 90-min loading/unloading sessions during the driving day, one in the morning and one in the afternoon.

Drivers wore wrist actigraphs for 48 hr preceding the start of the experiment to establish a rested state at the beginning of the experiment and to observe the driver's habitual sleep habits. The Stanford Sleepiness Scale, driver subjective ratings of tiredness, were administered at the end of each driving or loading/unloading period. The drivers were housed in an apartment near the test site but were not confined to the apartment or physically monitored during the duty week. Drivers were instructed to get a good night's sleep each night at the apartment. Actual sleep was verified by wrist actigraphy. During recovery days, the driver remained in his lodging. Drivers were allowed to leave the residence area for short trips to eat, exercise, or perform other normal activities.

During 90-min scheduled driving periods, performance measures were maintained and recorded and compiled into 10-sec time periods. Driving performance measures were drawn from built-in parameters associated with the simulator (FAAC DTS-2000) plus computer generated video imagers of driver appearance. The simulator database includes 87 mi of varied highway, including urban and rural roads, divided highway, and primary and secondary road. Urban areas include buildings. (Note: Authors did not describe which types of roads were used in testing.)

Driving runs were conducted using 12 preset scenarios, each consisting of a fixed route designed to take approximately 90 min to complete at the posted speed limits. The DTS-2000 measures included lane position, shifting performance, brake usage, and response probes (e.g., psychomotor response time to driving computer-mediated scenarios). Response probes (e.g., traffic stop, lane cross, etc.,) were used as a primary measure of driver performance (and represent a departure from typical studies of this type) and provided tests of driver vigilance, alertness, and response time. Driver response was evaluated by expert trainers based on a three-point scale.

During driving days a Psychomotor Vigilance Task (PVT) was administered 3 times (0645, 1330, and 2100). Subjective examination of video records of drivers during simulated operations were conducted for samples taken from periods during which parallel indicators showed evidence of good or poor performance.

Multiple measures were employed to gauge recovery, including sleep patterns, sleep latency, subjective sleepiness, and the PVT. These measures were repeated regularly 4 times each day (0900, 1300, 1700, and 2100) during the 58-hr rest and recovery period.

Scope of Work: Study consisted of focus groups, a driver survey and interviews with CMV drivers focused on the physical requirements (loading/unloading) across the industry. This was followed by a driving simulator study.

Sample Size: 10 male truck drivers with long-haul truck driving backgrounds; aged 31 to 49, mean = 43.2

Industry Sector: CMV drivers

Major Limitations:

1. Small number of subjects (n = 10). Subjects were studied in a simulator environment rather than a real-world setting.
2. As only a straight day schedule was examined, the conclusions drawn regarding the amount of cumulative fatigue and amount of recovery are restricted to this single schedule.

3. Subjects were directed to take breaks of a specific length and told to get a good night's sleep. As a result subjects may have not been as fatigued as drivers at the end of a week of driving in a real-world setting. This has implications for the conclusions that can be drawn regarding the amount of cumulative fatigue and amount of recovery time needed.
4. As subjects stayed at an apartment when not on duty during their driving week, the amount/quality of sleep they experienced may not be indicative of the sleep they would experience on the road. In addition, the amount of rest they had on the rest days may also be inflated, as social distractions in their home setting were not present.

Findings

With respect to when there was evidence of fatigue in relation to cumulative time/days on task:

1. There was a gradual decline in driver response quality over time (hours at the wheel). There were slight performance degradations in the mid-afternoon, but there were improvements after each break, whether for rest, meals, or loading activities. The authors did not discuss how long the improvement effect lasted.
2. The rest breaks had an influence on critical safety measures. For example, the effects of 6.5 hr of driving were reduced to starting levels by the 1-hr lunch break for non-loading days. While the recovery effect of a rest break is not surprising, the magnitude of the effect is striking. (Note: As the loading/unloading variable contributed to a significant interaction it is of use to examine the days when no such activity occurred, since these are more typical of the industry as a whole, and are free of the loading/unloading variance).
3. After the morning physical activity, there was an improvement in driver response to crash-likely simulated situations, probably due to a short-term invigorating effect associated with physical exercise and a break in driving routine.
4. The afternoon loading/unloading session did not have the same effect on drivers. Driving performance deteriorated more rapidly after the afternoon physical activity, suggesting that cumulative physical/general fatigue and time-of-day effects are sufficient to overpower some short-term effects of a change in activity. Driving performance did return to starting levels near the end of the day.
5. The ability to maintain speed within posted limits and gear shifting performance both deteriorated somewhat during the latter part of the driving day. The simultaneous occurrence of the two suggests deterioration in physical coordination and vigilance late in the day, but there was no consistent linear relation to hours of driving.
6. The authors note that there is "no useful way to compare the cumulative effects of the 14/10 schedule with other possible schedules (including those logically subsumed, such as 10-hr and 12-hr duty periods) because the cumulative effects for each are confounded." However, what can be said about cumulative effects is that they "appear to be nil for practical measures (e.g., probe scores) and mild for parallel subjective measures such as subjective sleepiness." Duty-day subjective sleepiness, reaction time response, and measures of driving performance showed a slight but statistically significant deterioration over the driving week, but driver response in crash-likely situations did not show cumulative deterioration. The schedule of 14 hr on duty/10 hr off duty (12 hr driving) for a 5-day week did not appear to produce significant cumulative fatigue over the 2-week testing period.
7. The mean sleep times recorded for the driving days were as follows:

   - Day 1 = 6.870; SD = 1.286; n = 10
   - Day 2 = 6.454; SD = 0.685; n = 10
   - Day 3 = 6.351; SD = 1.055; n = 10
   - Day 4 = 6.215; SD = 0.921; n = 10
   - Day 5 = 6.516; SD = 0.823; n = 10

   Average: 6.4812

- Days 6 and 7: rest days
- Day 8 = 6.201; SD = 1.104; n = 10
- Day 9 = 6.383; SD = 0.636; n = 10
- Day 10 = 6.447; SD = .619; n = 10
- Day 11 = 6.038; SD = 0.806; n = 10
- Day 12 = 6.026; SD = 0.954; n = 10

Average: 6.219

- Days 13 and 14: rest days
- Day 15 = 5.666; SD = 1.228; n = 10

With respect to time to recovery (of performance, level of alertness)

1. The authors did not discuss differences in the rate of deterioration of driving performance between the first and second week.
2. The mean sleep times for the recovery days were as follows:

   - Day 6 = 6.364; SD = 1.315; n = 10
   - Day 7 = 7.438; SD = 1.1251; n = 10
   - Day 13 = 6.745; SD = 1.061; n = 10
   - Day 14 = 7.778; SD = 1.708; n = 10

3. While there was an increase in measured sleep and a decrease in sleep latency on the first off-duty rest day following the end of the driving week, the authors do not believe that the peak sleep periods during the "weekend" days were due principally to sleep deprivation. They noted that drivers varied in the number of hours of sleep per night, and in a by-case examination of driver sleep patterns did not show a higher rebound for those who slept less during the driving week, indicating that the variation observed did not represent deprivation. They felt that the drivers did not appear to have accumulated significant sleep loss.
4. Sleep latency was measured between 2200 and 2230 on the last driving day (Friday) of each week. At this point, drivers were not ready to sleep, however tired they might have felt, since they had just been released from a 14-hr driving day. The second sleep latency measurement was taken between 0900 and 0930 the next morning (Saturday), shortly after the drivers had awakened from a night's sleep. The third sleep latency measurement was taken at 1300 on Saturday and proved to be dramatically the shortest sleep latency.
5. Drivers returned to baseline reaction time performance and alertness within 24 hr after the end of a driving week, as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. This effect was generally consistent across drivers. The typical recovery pattern involved extra sleep during the first rest day verified by wrist activity monitor, and an increased level of sleepiness during the afternoon of the first day (indicated by shorter sleep latency).

With respect to individual differences

6. Age was correlated with lane performance ($r = .508$, $p < .01$) and shifting performance ($r = -.287$, $p < .01$).
7. Height/weight (a surrogate measure for general fitness) was correlated with lane performance ($r = -.358$, $P < .001$) and shifting performance ($r = -.428$, $p < .001$).

(Word of caution: While strong correlations with age and height/weight appeared with largely physical tasks, they were absent or negligible in other variables such as mean probe score.)

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 37, FHWA-MC-99-140, *". . . there is "no useful way to compare the cumulative effects of the 14/10 schedule with other possible schedules (including those logically subsumed, such as 10-hour and 12-hour duty periods) because the cumulative effects for each are confounded. The most that can be said about cumulative effects is that they "appear to be nil for practical measures (e.g., probe scores) and mild for parallel subjective measures such as subjective sleepiness."*

p. 3, FHWA-MCRT-99-008, *"Drivers returned to baseline reaction time performance and alertness within 24 hours after the end of a driving week, as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. In daytime driving schedules like this one, resuming work after 24 hours of rest would cause severe circadian disruption. Drivers ought to resume duty only after a minimum of 36 hours rest."*

Driver Duration

p. 40, FHWA-MC-99-140, *". . . simple time on task is not a uniformly effective determiner of performance. Factors such as time-of-day (and its relation to circadian cycle) and rest break schedule are so influential that other factors customarily associated with performance deterioration over time are dwarfed. In this case, it is a reasonable observation that, in a typical day (morning to evening) shift, the difference between a 10- or 12-duty day and a 14-hour day is negligible. We caution, however, that this observation cuts both ways with respect to the suitability of a 14-hour duty schedule. We cannot say with certainty that this result would be observed with other than a day shift, since the powerful effects of circadian factors could interact with time on task and length of duty to produce very different results for different shift schedules."*

p., 41, "FHWA-MC-99-140, *"From the results of this study, we find no reason to believe that a schedule of 14 hours on duty, 12 hours driving, followed by 10 hours off duty, is likely to cause noticeable performance decrement on drivers, and it has the advantage of allowing five days of continuous work at such a schedule without the complication of offsetting the 24-hour circadian rhythm. That is, such a regularized 14/10 schedule permits drivers to maintain their work schedules in parallel to expected circadian body rhythm changes in physiology and performance. This conclusion is limited to conditions in which the driver is (1) conditioned or accustomed to the schedule being followed (that is, a change in shift that upsets the circadian rhythm would in all likelihood negate the 14/10 schedule much as it would a 16/8 or 12/12 or any other notional schedule); (2) the driver is allowed a reasonable break schedule; (3) the driving is accomplished on a typical day shift pattern (since night driving was not tested in this study); and (4) the off-duty time is actual off-duty time during which a driver may obtain sleep."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewer: Dianne Davis

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

Abstract: This paper summarizes the results of a survey of CMV drivers in 116 trucking firms. The purpose of the study was to identify factors (i.e., fatigue inducing and company safety management factors) relevant to the prediction of driving while fatigued, close calls due to fatigue and actual crash involvement among CMV drivers engaged in intra- and interstate truck driving work. "Findings indicated that fatigue-inducing factors inherent in driving work and safety practices accounted for appreciable variation in driving fatigued (R squared = 0.42) and close calls (R squared = 0.35), but not crash involvement. Driving while fatigued also accounted for incremental increases in the amount of variation in close calls, after consideration of inherent factors and safety practices." The authors concluded "that safety practices (e.g., establishment of a strong safety culture, dispatcher scheduling practices, company assistance with fatiguing behaviors such as loading and unloading) have considerable potential to offset fatigue-inducing factors associated with truck driving work."

Methodology: This paper summarizes the results of a survey of CMV drivers in 116 trucking firms. Thirty-two of these firms were top safety-performing firms, 53 from average firms, and 31 from poor performing firms. Drivers were asked a number of questions about fatigue-inducing factors such workload, schedule regularity, difficulty finding rest places, adequacy of sleep, insufficient recovery, percent of time loading/unloading. In addition, participants were asked about the perceived safety climate in their company. The authors formulated 11 perceived safety climate items (e.g., "Our Company makes driving safety a top priority") and asked drivers to record their level of agreement). Finally drivers were asked about their fatigue while driving (e.g., nodding off while driving, etc.,), as well as frequency of close calls and crashes. The authors proposed three models to account for the variation in fatigue while driving, close calls due to fatigue, and crash involvement. Proposition 1 specified that fatigue inducing factors would account for variation in these outcome measures. Proposition 2 specified that "company safety management practices should account for variation in the outcome measures, controlling for fatigue-inducing factors associated with truck driving work." Proposition 3 contended that "fatigue while driving accounts for variation in the frequency of close calls due to fatigue and crash involvement, after controlling for fatigue-inducing factors and company safety management practices."

Scope of Work: Survey conducted with CMV drivers. A literature review was conducted on fatigue-inducing factors, work overload, schedule regularity, disturbances in sleep patterns, insufficient recovery, and company safety management practices.

Sample Size: Survey of CMV drivers in 116 trucking firms. At least one driver provided usable data from each firm. (4% female, 96% male; ages: 22 to 63; average age = 43; average number of driving years: 14.92).

Industry Sector: CMV drivers

Major Limitations: The authors conclude their paper with a summary of the limitations of their research. They state that the primary limitations of this research are that it involves "potential sampling bias (e.g., low percentage of firms agreeing to participate in the project, safety director selection of drivers), the use of measures without established validity, and reliance on single item measures for the independent variables. In addition, they point out concerns with the reliance on driver self-report, and the possible limitation in the restriction in range associated with the self-report crash involvement measure.

Findings

1. "Fatigue-inducing factors inherent in driving work and safety practices" (e.g., schedule regularity, difficulty finding a place to rest, adequacy of sleep when working, insufficient

recovery, percent of time loading/unloading, etc.) "accounted for appreciable variation in driving fatigue (R squared = 0.42) and close calls (R squared = 0.35), but not crash involvement." Self-report measures were used to assess fatigue (i.e., 3-item measure). Crash involvement was measured using the sum of two items: (1) reportable accidents (to the company) and (2) chargeable accidents that drivers had been involved with over the last 2 years. Approximately one-fifth of the drivers reported having one or more reportable accidents, and approximately 4% reported having chargeable accidents. The raw data was adjusted to account for exposure and expressed on a per 100,000 mi basis. Drivers with reportable accidents had between 0.32 and 6.41 crashes per 100,000 mi, while those reporting chargeable accidents had between 0.29 and 1.03 crashes per 100,000 mi. The measure exhibited a Cronbach alpha of 0.85.

2. "Driving while fatigued accounted for incremental increases in the amount of variation in close calls, after consideration of inherent factors and safety practices."
3. ". . . Safety practices (e.g., establishment of a strong safety culture, dispatcher scheduling practices, company assistance with fatiguing behaviors such as loading and unloading) have considerable potential to offset fatigue-inducing factors associated with truck driving work."
4. While there is an assumption that employees will use off-duty time to engage in restorative activities, the insufficient recovery results reported in this study led the authors to conclude that "drivers do not necessarily spend their non-work time in this manner." While drivers may not engage in job-related activities during their recovery periods, some drivers do engage in activities and sleep patterns that lead them to report back to work already fatigued. The authors note that the results "suggest that the potential misuse of off-duty time can be mitigated by the presence of a strong safety climate or enactment of policies targeted at fatigue-inducing activities (i.e., companies can act to reduce this problem)."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 63, *"Insufficient recovery was gauged by asking drivers how frequently they began a new "workweek" feeling tired or fatigued." Just over half (53%) said this never or only rarely happened to them (scored "1") while 47% indicated that this happened with greater frequency (scored "2")."*

p. 65, *"Fatigue-inducing factors, especially insufficient recovery, appear to play a role in determining whether a driver experiences fatigue and close calls due to fatigue."*

p. 65, *"The amount of time spent loading and unloading trucks appears to have a bearing on crash involvement, though the overall role of fatigue inducing factors was not predictive of crash involvement."(i.e., more loading and unloading was associated with negative impacts).*

p. 65, "*The joint ability of fatigue-inducing factors and safety practices accounted for 42% ($p < .001$; Model 1) of the variation in fatigue while driving."*

p. 66, "*Contrary to expectations, policies to minimize driving at night appeared to increase the frequency of close calls due to fatigue. However, it should be noted that policies to minimize nighttime driving were negatively related (albeit non-significantly) to fatigue while driving (beta = −.10, ns; Model 1), leaving the utility of this practice open to further debate."*

p. 66, "*Schedule regularity, difficulty in finding a place to rest, and insufficient recovery remained statistically significant contributors to the model."*

p. 66, "*Proposition 3 asserted that fatigue while driving accounts for variation in the frequency of close calls due to fatigue and crash involvement, after controlling for fatigue-inducing factors and company safety management practices . . . We conclude that Proposition 3 was supported in the case of close calls but not in the case of crash involvement."*

p. 66, "*The models tested herein were able to account for modest amounts, around 40%, of the variation in fatigue and close calls dues to fatigue, but were unsuccessful in explaining crash involvement. While close calls ("near accidents") are often used as proxies for crashes, these findings indicate that each outcome has unique antecedents and thus may require different explanations (e.g., percent of time spent loading was observed to be a good predictor of crashes but not related to fatigue or close calls.").*

Driver Duration

p. 63, "*The number of 6-hour time blocks driven in the course of a day was measured by asking drivers to specify the time blocks they normally spent more than 10% of their driving time: 6 a.m. to noon, noon to 6 p.m., 9 p.m. to midnight, and midnight to 6 a.m. . . . Just over half the drivers (50.9%) were able to limit their blocks to two, 27.6% reported three time blocks and 12.5% reported that they commonly worked during all four time blocks.*"

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewer: Dianne Davis

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

Abstract: The aim of the study was to investigate the relationship between staged driving and fatigue. Professional truck drivers completed a 12-hr, 900 km trip under each of three driving regimes—a relay (staged) trip, a working hours regulated one-way (single) trip, and a one-way (flexible) trip with no working hours constraints. All of the observed trips took place overnight. The authors concluded "although there was some evidence that fatigue developed differently within the three driving regimes (staged, single, and flexible), the levels of fatigue experienced by drivers increased markedly over all the trips. None of the regimes demonstrated any overall advantage in combating fatigue compared to the other regimes." The authors conclude that it is clear from their findings that even relatively short 12-hr trips are tiring and that effective strategies for fatigue reduction need to be identified. In addition, their finding that pre-trip level of fatigue appears to be an important determinant of later fatigue raises questions about the ongoing work schedules under which long distance drivers operate, "and highlights the need to allow adequate rest and recuperation between trips and between blocks of trips to prevent chronic sleep loss and to reduce fatigue."

Methodology: Professional truck drivers completed a 12 hr, 900 km trip under each of three driving regimes—a relay (staged) trip, a working hours regulated one-way (single) trip, and a one-way (flexible) trip with no working hours constraints. "The staged trip entailed driving from Sydney or Melbourne to the trip midpoint (Tarcutta), exchanging trucks or loads with a driver coming in the opposite direction, and then returning to the point of origin." The single one-way trips involved driving directly from Sydney to Melbourne, and the flexible one-way trips involved driving from Melbourne to Sydney." "Under the regulations, drivers on single and staged trips were obliged to break for 30 min after each 5-hr period. Under the flexible regime drivers could choose to take breaks as often or as rarely as they needed with no constraint on the time taken to complete the trip." All of the observed trips took place overnight. Most trips began in the early evening and night between 1600 and 2359. The three driving regimes did not differ significantly in starting time. While, on average, the staged trips took longer to complete than the flexible trips, the trip lengths differed by only 40 min. The study employed subjective (e.g., Stanford Sleepiness Scale, etc.), physiological (e.g., heart rate), and performance (e.g., speed, steering variability, reaction time, etc.) "measures to examine the relationship between the characteristics of staged driving and the development of fatigue."

Scope of Work: Field study with professional truck drivers who routinely ran staged operations between Sydney and Melbourne in Australia.

Sample Size: Twenty-seven professional truck drivers (average age = 38.4; average years of commercial driving = 15.9 years

Industry Sector: Professional truck drivers

Major Limitations: The authors note that further investigation is needed to determine whether these findings would generalize to longer trips where there is greater potential for flexibility in break-taking to be effective.

Findings

1. "Although there was some evidence that fatigue developed differently within the three driving regimes (staged, single, and flexible), the levels of fatigue experienced by drivers increased markedly over all the trips."
2. "None of the regimes demonstrated any overall advantage in combating fatigue compared to the other regimes."

3. It is clear from the findings that "even relatively short 12-hour trips are tiring, and that effective strategies for fatigue reduction need to be identified."
4. Pre-trip level of fatigue appears to be an important determinant of later fatigue. This raises questions about the ongoing work schedules under which long distance drivers operate, "and highlights the need to allow adequate rest and recuperation between trips and between blocks of trips to prevent chronic sleep loss and to reduce fatigue."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 713, *"Both the Stanford Sleepiness Scale ratings and the visual analogue scale ratings (Table 2) revealed a marked increase in fatigue between the beginnings and ends of the trips for all trip types."*

p.. 713, *"Drivers tended to feel most fatigued on staged trips and least fatigued on single trips, however, this pattern was in evidence before driving commenced and at posttrip had not been modified by the intervening driving regime."*

p. 715, *". . . drivers' performance on the vigilance, critical flicker fusion and unstable tracking tasks suggested heightened fatigue at the start of the staged trip, and for vigilance and unstable tracking, this impaired performance under the staged regime was maintained across the course of the trip. These findings are consistent with the higher fatigue ratings given by drivers before and after the staged trip."*

p. 717, *"Over all measures, the pattern of results suggests that fatigue increased across all trip types . . . There is clearly a need to identify those factors affecting the drivers' pretrip fatigue and performance."*

p. 718, *". . . the pretrip level of fatigue appeared to be an important determinant of later fatigue. This finding raises questions about the ongoing work schedules under which long distance drivers operate, and highlights the need to allow adequate rest and recuperation between trips and between blocks of trips to prevent chronic sleep loss and to reduce fatigue."*

Driver Duration

p. 712, *"The number of breaks taken (Table 1) increased across flexible, single, and staged trips, suggesting an increasing need for rest as a function of driving regime. However, breaks were taken after similar periods of driving for the three trip types (Table 1). The longest driver period (4.5 hours) routinely occurred before the first break and the shortest drive period (2.5 to 3 hours) preceded the second break."*

p. 712, *"In summary, the pattern of break-taking suggests increased fatigue around the middle of the trips and greater overall fatigue on staged trips. However, these conclusions need to be treated cautiously because break-taking may have occurred for reasons other than providing a rest from driving, and at times of convenience, necessity or habit."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

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

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

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

The second and third reports focused on four evaluations, consisting of two evaluations of the current working hours regulations in New Zealand and two evaluations of alternative approaches to work-rest schedules. All the evaluations except one (a simulation) were conducted on-road using the performance measures developed in the first step of this project. Participants started the study after being on break for 24 hr to "obtain baseline information about performance when rested." Ratings of fatigue and performance were then taken at "strategic points across the work-rest schedule between two long 24 hour breaks."

The alternative approaches to work-rest schedules were evaluated in a simulation study and an on-road study. The simulation study looked at the extension of the daily working hours limit from a "maximum of 14 hours in a 24-hour period to up to 16 hours in a 24-hour period. The overall schedule covered 60 hours. The longer hours were balanced by beginning and ending the schedule with a 6-hour break and having a mandatory 6-hour break at some point in the intervening 48 hours. Short breaks of at least 15 minutes were also required after every 3 hours of work. The evaluation was conducted as a simulation because it had not yet been authorized to be trialed on the road as part of the pilot FMP." In contrast, the second evaluation of an alternative approach to work-rest schedules could be conducted on the road because "it was in operation as part of the pilot FMP". It "differed from the regulated hours regime by allowing for longer sustained periods of work at a stretch and splitting of the mandatory breaks between them. The regulated hours allow only 5 continuous hours of work before drivers take a break of at least 30 minutes. In this alternative schedule, drivers could work up to 6 continuous hours and only needed to take breaks in 15-minute periods, although they needed to take 30 minutes in total in every 6 hour period. The FMP also allowed drivers to divide the mandatory 6 hour continuous break into shorter sections. In all other ways, the work-rest schedule was the same as the regulated regime."

Scope of Work: Identification of performance measures sensitive to fatigue and evaluations of current and alternative working hours regulations.

Sample Size: Not stated

Industry Sector: Professional drivers

Major Limitations: The evaluation of regulated hours only reflects the effects of one cycle of the current regime on drivers who had low levels of fatigue to begin with. "Further research is needed to look at how the regulated regime manages fatigue over the longer term."

Findings

1. While most of the tests showed deterioration in performance with increasing alcohol doses, not all the tests did so for increasing sleep deprivation.
2. The tests chosen to be most sensitive to fatigue were Simple Reaction Time, Mackworth Clock Vigilance test, and Dual Task.
3. ". . . 0.05% BAC equivalence occurred at between 17 and 19 hours of sleep deprivation for most tests. This means that after around 17 hours of wakefulness, performance capacity was sufficiently impaired to be of concern for safety."
4. There was little evidence that current working hours led to performance decreases large enough to "constitute a significant safety risk compared to alcohol equivalent levels at 0.05% BAC."
5. In the simulation study of an alternative compliance approach, drivers were able to manage fatigue effectively over the first 16 hr of the schedule, however, their performance deteriorated significantly by the middle of the second 16-hr period. Performance at this time was "considerably poorer than the 0.05% BAC alcohol equivalence standard. It seems that the 6 hour break was insufficient to allow recovery and recuperation from the demands of the previous long day . . ." The work-rest schedule was "too demanding for drivers to manage fatigue effectively."
6. The results of the road test evaluation of the second alternative compliance approach showed that "reaction speed showed a deterioration across the study to levels that were suggestive of an increased safety risk based on the 0.05% BAC equivalent standard for performance."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 2, *"Through a careful comparison of alcohol and sleep, performance capacity has deteriorated sufficiently to be of concern to the community due to an increased potential safety risk."*

p. 3, *"For the first evaluation of the regulated regime (CR 190, Evaluating a regulated hours regime on-road and an alternative compliance regime under simulated conditions) fatigue ratings were significantly higher when drivers returned to the depot at the end of the first trip and at the end of the study period compared to rested levels. Despite this, there were only a few significant changes in performance capacity."*

p. 11, For evaluations of regulated regime: "*Both evaluations showed, however, that performance capacity deteriorates and fatigue levels increase in relation to factors like increasing hours of work (especially night hours), short breaks and breaks that only allow short or poor quantity sleep (see Table 3). While fatigue and performance capacity seem to be maintained with safe limits under the regulated regime, these findings indicate that where drivers or companies take the work-rest schedules beyond the current limits, they are likely to be increasing the risk of performance decrements sufficient to compromise safety."*

Driver Duration

p. 20, *"Evaluation of the current working hours regime suggests that provided drivers are rested to begin with, one full cycle of the regulated regime does not produce fatigue or performance capacity decrements that are of concern for safety. There is considerable evidence however that performance decrements increase significantly as the schedule becomes* *more demanding. This is a warning signal for the development of alternative approaches to ensure that schedules are designed that do not simply increase the demands on drivers. The evidence from both evaluations of alternative compliance schedules suggested that they increased the demands on drivers, but did not balance them sufficiently with rest in order to allow recuperation and recovery from accumulated fatigue."*

p. 20, "These results do not mean that the working hours regulatory regime is the only satisfactory approach to managing fatigue. The results show clearly that it is possible to increase trip length to 16 hours, say, and still maintain good performance levels. It is not possible, however, to continue to do 16 hour trips without a longer break than is usually allowed, even in the regulated regime."

p. 13, "Long work periods need to be balanced by longer rest periods. This study did not address the issue of the length of rest needed to recover sufficiently from a 16 hour work period. It only showed that a 6 hour break was not sufficient."

Driver Health

No significant findings or assumptions concerning impact on health are stated in summary.

Reviewers: Dianne Davis, Alison Smiley

Titles:

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

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

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

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

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

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

Methodology: The study used a between-subjects design involving four driving schedule conditions: C1: 10-hr daytime (5 consecutive days); C2: 10-hr rotating (5 consecutive days, starting 3 hr earlier each day); C3: 13-hr nighttime start (4 consecutive days); C4: 13-hr daytime start (4 consecutive days). The study design "was developed to comply with existing U.S. and Canadian hours-of-service regulations." "The four schedules provided different amounts of time off between trips. Condition 1 provided about 11 hours off, while the other three conditions provided about 8 hours off." Various measures were taken: driving task performance (e.g., lane tracking, steering wheel movement), driving speed and distance monitoring, performance on surrogate tests (i.e., code substitution, critical tracking test, simple response vigilance test), continuous video monitoring, physiological measures as well as driver-supplied information (e.g., daily logs, Stanford Sleepiness Scale rating). A follow-up study focused on five groups of CMV drivers. One group of five drivers worked nights (i.e., 4 × 13-hr nights, followed by 36 hours off, and then worked 4 × 13-hr nights) and the remaining four groups worked days. Three of the groups worked 4 × 13-hr days and had varying recovery time (i.e., group 1: 10 to 11 hr, three drivers; group 2: 36 hr, six drivers; group 3: 60 hr, six drivers) before working an additional day. The final group of five drivers worked 4 × 13-hr days, had 36 hr off and worked 4 additional days.

Scope of Work: Literature review. Field study involving Canadian and American CMV drivers.

Sample Size: 80 male CMV drivers; 25 to 65 years old

Industry Sector: CMV drivers

Major Limitations: "The limitations of the study relate primarily to the lack of full control over the full range of conditions affecting alertness and fatigue and the inability to isolate some factors due to unavoidable confounding of variables, a consequence of the naturalistic approach to this study."

Findings

1. Time of day was far more important than time on task or cumulative number of trips in predicting driver fatigue.
2. Drivers in the C3: Nighttime condition had the least amount of sleep of all the conditions.
3. "Night driving (e.g., from midnight to dawn) was associated with worse performance on four important criteria" (e.g., average lane tracking standard deviation, drowsiness, code substitution, and sleep length).
4. "There was some evidence of cumulative fatigue across days of driving. For example, performance on the Simple Response Vigilance Test declined during the last days of all four conditions."
5. Drivers had approximately 2.5 hr less sleep than the amount of sleep they identified as their ideal.
6. Drowsiness in Conditions C3: Nighttime and C4: Daystart was markedly greater during night driving. Of episodes of drowsiness during on-road driving, 82% occurred between 1900 and 0659.
7. The follow-up study found that based on a small sample of drivers, 36 hr recovery was insufficient for day or night drivers, but especially for night drivers.

Findings Directly Related to HOS (include page references):

Note: All following quotes are from Wylie 1996.

Driver Fatigue/Alertness

p. ES-8, *"The strongest and most consistent factor influencing driver fatigue and alertness in this study was time of day."*

p. ES-9, *"Night driving (e.g., from midnight to dawn) was associated with worse performance on four important criteria . . ." (i.e. average lane tracking standard deviation, drowsiness, code substitution and sleep length).*

p. ES-9, *"There was some evidence of cumulative fatigue across days of driving. For example, performance on the Simple Response Vigilance Test declined during the last days of all four conditions."*

p. ES-10, "*Overall, drivers obtained about 2 hours less time in bed and 2.5 hours less actual sleep than their reported "ideal" daily amount of sleep."* (i.e., ideal = 7.2 hr; actual sleep during study = 5.2 hr).

p. 4-23, *"The overall pattern was characterized by the longest sleep times in Condition C1-10day and the shortest in Condition C3-12nightstart . . ."* (Total sleep time for: C1-10day = 5.4 hr; C3-13nightstart = 3.9 hr)

p. 4-33, *"The observed prevalence of drowsiness formed a distinct peak about 8 hours wide, spanning late evening until dawn, and a 16-hour trough."*

p. 4-32, *"The prevalence of drowsiness in conditions C3-13nightstart and C4-13daystart was markedly greater during night driving."*

p. 4-42, *"There was probably greater drowsiness in Condition C2-10rotating, trips 4 and 5, because the rotating schedule had caused these last trips, on average, to be driven through the night. Although disruption of circadian rhythms and cumulative fatigue probably contributed, time of day appeared to be a major factor."*

Driver Duration

p. ES-9, *"Hours of driving (time-on-task) was not a strong or consistent predictor of observed fatigue."*

Driver Health

No significant findings or assumptions concerning impact on health.

SUMMARY OF FINDINGS OF LITERATURE

The review of sources from the period 1996 onward supports evidence in previous findings as follows:

- Falling asleep at the wheel is a common experience for truck drivers.

  In a study of 567 drivers, almost one-fifth reported falling asleep at the wheel twice in the last 3 months (Hakkanen and Summala 2000). These are self-reports; the reality is likely to be more.
- Night driving is associated with poor sleep.

  Of 4 schedules, drivers in the 13-hr night driving condition had the least sleep (3.9 hr total) (Wylie et al. 1998).
- Night driving is associated with more falling asleep incidents.

  Of episodes of drowsiness during on-road driving, 82% occurred between 1900 and 0659 (Wylie et al. 1998).
- Long-haul drivers get poor sleep.

  A comparison of long-haul and short-haul drivers found both obtained 7.5 hr sleep on average. However, long-haul drivers obtained 44% of their sleep during work-shift hours, suggesting that they spend a significant portion of the work shift in a state of partial sleep deprivation. (Balkin et al. 2000).
- Night driving is associated with poorer driving performance.

  Lowered performance was found for drives of 1.5 hr in a simulator (Gilberg et al. 1996), and for nighttime on-road driving typical of trucking schedules (Wylie et al. 1998).
- Reduced sleep at night is associated with poorer daytime performance and with inadequate recovery.

  A laboratory study of the effects of restricted night sleep on daytime simulator performance showed that reduced sleep is associated with poorer performance and that recovery to baseline requires more than 1 night of 8-hr sleep for those with 3, 5 or 7 hr in bed during the work week. For the 3-hr group, even 3 recovery nights of 8-hr sleep is not sufficient (Balkin et al. 2000).
- Dangerous events are related to sleep deficit and prolonged driving.

  In an on-road study, 20% of 1,249 drivers with less than 6 hr sleep had 40% of the critical incidents (Arnold et al. 1997). Frequent sleepiness-related problems occurred in one-half of drivers who reported a combination of sleep deficit, prolonged driving, and lower self-perceived health (Hakkanen and Summala 2000).
- Driving while fatigued increases likelihood of close calls.

  Driving while fatigued resulted in an increase in the variation in close calls, after inherent factors and safety practices were controlled for (Morrow and Crum 2004). Drivers involved in critical incidents were younger and less experienced and more likely to exhibit on the job drowsiness (Hanowski et al. 2000).
- Time of day is far more important that hours of driving in predicting observed fatigue.

  Time of day was far more important than hours of driving (time on task) or cumulative number of trips in predicting fatigue (Wylie et al. 1998).

Sources dating from 1996 onward contain new findings as follows:

- Under ideal circumstances, long daytime hours with good sleep are not a problem.

  In a laboratory study, performance in the 7 and 9 hr time in bed groups was often indistinguishable and improved throughout the study. With 7 hr time in bed, impaired performance was only found on the more sensitive tasks. When sleep was restricted to 8 hr time in bed during recovery, performance of the group who had received 9 hr time in bed was slightly worse (Balkin et al. 2000). In a second laboratory study, the schedule of 14 hr on duty/10 hr off duty for a 5-day week did not appear to produce significant cumulative fatigue (O'Neill et al. 1999). However, subjects slept in an apartment and may not have been subject to normal home distractions, resulting in more sleep than usual.
- Night sleep is important for recovery from a single day of driving and from several days of driving.

  A dramatic recovery with respect to fatigue was found in team drivers who stopped overnight in the middle of a 4- to 5-day trip (Feyer et al. 1997). A small study that examined 0-hr, 36-hr, and 60-hr recovery found that only partial recovery occurs after a 36-hr reset for both day and night drivers (Wylie et al. 1998).
- Single drivers were more involved in incidents than team drivers.

  In an on-road study, single drivers were involved in four times more instances of very/extremely drowsy observer ratings than were team drivers and were more likely to push themselves when they were very tired (Dingus et al. 2001).
- Insufficient recovery is related to close calls.

  Fatigue-inducing factors, especially insufficient recovery, are statistically associated with a driver experiencing fatigue and close calls due to fatigue (Morrow and Crum 2004).
- Starting the work week feeling fatigued is a common experience for CMV drivers.

  Almost half of CMV drivers indicated that they started a new "work week" feeling tired more than "rarely" (Morrow and Crum 2004). In a study of team versus single drivers, team drivers started the week tired (Feyer et al. 1997).
- Dangerous events related to drivers' self-perceived health status.

  With respect to health, there were increased odds of drivers having more frequent difficulties in remaining alert if the driver had poorer self-perceived health (Hakkanen and Summala 2000).

- Poorer lane tracking and gear shifting related to poorer general fitness.

  Height/weight (a surrogate measure for general fitness) was correlated with lane performance and shifting performance. These correlations were absent for more cognitive, less physical tasks (O'Neill et al. 1999).

RESEARCH LIMITATIONS

The most notable lack of research concerns recovery requirements, particularly for night drivers. Long-distance truck drivers frequently drive at night to avoid traffic and, because they work at night, must sleep during the day. Because of circadian rhythms, we do not perform well at night, particularly during the early morning hours, and sleep obtained during the day is shorter and of poorer quality than sleep obtained at night. Currently, HOS regulations treat daytime and nighttime driving equally both in terms of hours permitted and required recovery time. The new regulations will allow for longer hours in a 7-day period provided the driver takes a 34-hr reset period. Research concerning the acceptability of this reset period is very limited (a laboratory study of daytime performance finding good recovery after 1 night of sleep if previous night's sleep had been 7 or 9 hr, a study of team drivers in a remote area of Australia finding dramatic recovery after a single overnight stop in the middle of a 4- to 5-day trip, a small on-road study showing that neither day nor night drivers, and especially not night drivers recovered fully following a 36-hr reset).

COMPLETE PRIMARY SOURCES AND ABSTRACTS

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

Drivers and companies operating in the heavy road transport industry were surveyed about drivers' hours of work and perception of the causes and magnitude of fatigue as an industry problem. These drivers were operating in a state which, at the time of the survey, did not restrict driving hours for heavy haulage drivers. On the day of the interview, estimates based on retrospective and prospective reports, suggest that in a 24-hr period about 38% of drivers exceed 14 hr of driving, and 51% exceed 14 hr of driving plus other non-driving work. About 12% of drivers reported less than 4 hr of sleep on 1 or more working days in the week preceding the interview. These drivers are likely to be operating their vehicles while having a significant sleep debt. About 20% of drivers reported less than 6 hr sleep before starting their current journey, but nearly 40% of dangerous events that occurred on the journey were reported by these drivers ($p < 0.05$). Many drivers and company representatives reported fatigue to be a problem for other drivers, but considered themselves or their companies' drivers to be relatively unaffected by fatigue. There were differences between drivers' and companies' perceptions about causes of fatigue, and strategies that should be used to manage it. The results obtained from these drivers in an unregulated state were compared with earlier findings from drivers in states where driving hours restrictions are in place.

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

The Balkin et al. (2000) study involved an actigraphic assessment of the sleep of 50 long- and short-haul CMV drivers ages 21 to 65 for 20 consecutive days. The drivers wore the Walter Reed wrist actigraphs at all times except when bathing or showering. In addition, they completed sleep logs on driver's daily log sheets to gather subjective information about sleep times; sleep latency; arousals during sleep; alertness upon awakening; naps (number and duration); and self-reported caffeine, alcohol, and drug use. The data from each actigraph were downloaded to a personal computer, and each 24-hr actigraph recording period was examined for sleep in its entirety regardless of the duty status type or length indicated on the daily log sheet.

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

This paper presents recent research on compliance with current driving hours regulations, the effectiveness of using driving hours to predict fatigue, and alternative compliance and enforcement options. The paper describes results of a major survey of truck driver fatigue in New Zealand, a review of international compliance and enforcement procedures, and research focusing on the social forces and influences that affect truck drivers. The survey of truck drivers was based on interviews and performance tests collected from 600 truck drivers at depots, wharves, markets, and other locations throughout the North Island of New Zealand. The initial results from the first 100 drivers found a sizable number of drivers exceeding the allowable driving hours, high levels of fatigue and sleepiness, and interesting differences between line-haul and local delivery drivers. A related research project into the social processes/relationships that affect truck drivers has resulted in a good understanding of the social conditions that influence cultural change and the actions of truck drivers and fleet managers. In this paper we will have particular regard to these processes in the construction of ideas concerning safety. This includes an understanding of the role of major stakeholders, such as freight forwarders and the enforcement agencies with respect to drivers and their conditions, actions and understanding of the road transport industry. This knowledge coupled with the survey results and an understanding of compliance and enforcement alternatives will be used to explore potential fatigue management options. (a) For the covering entry of this conference, see ITRD abstract no. E204477.

AN: E204480

Charlton, S.G., and Baas, P.H. "Fatigue and fitness for duty of New Zealand truck drivers." (1998). Road Safety Research, Policing, Education Conference. Wellington, New Zealand. Vol. 2. pp. 214–9.

The effects of driver fatigue have been implicated in a large number of truck crashes and road fatalities in other countries. While there are no extensive studies of fatigue-related road accidents in New Zealand, the road characteristics and driving environment make any decrease in performance due to driver fatigue a significant potential threat to road safety. This paper describes an on-going Road Safety Trust-sponsored study of how common driver fatigue is in New Zealand and the degree to which these truck drivers suffer from fatigue related effects. Using a portable driving simulator installed in a caravan, volunteer truck drivers are asked to complete a brief survey (about their driving hours and their amount of sleep in the past 48 hr, how sleepiness affects them, and the level of fatigue they feel at that moment), and go for a "drive" on the driving simulator (measuring their vehicle control and reaction times) as they stop their trucks at depots, rest stops, and cargo terminals throughout the day and night. In comparison with indirect measures of fatigue, such as inspection of driving hours in log books, the fitness-for-duty test has obvious job relevance (measuring actual driving performance) and enjoys a high degree of driver acceptance.

FMCSA Tech Brief, 2001 (FMCSA-MCRT-01-006). "Impact of local/short-haul operations on driver fatigue: Field study."

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

Federal Motor Carrier Safety Administration. "Impact of sleeper berth usage on driver fatigue." (2002). Report Number: FMCSA-RT-02-050.

The goal of this project was to assess the impact that sleeper-berth use has on operator alertness. The participants in this study were 47 males and 9 females, constituting 13 teams and 30 single drivers. All drivers who participated in the study were recruited from one of four for-hire commercial trucking companies. Two tractors, a 1997 Volvo L4 VN-series tractor and a 1995 Peterbilt 379, with functionally identical instrumentation packages and data collection systems, were used. The data acquisition system functioned to record four camera views, including the driver's face; driving performance information, including steering, lane departure, and braking; sleeper-berth environmental data, including noise, vibration, and temperature; subjective alertness ratings; and data from the Nightcap sleep monitoring system. The results obtained are provided in the document.

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

This study is the fourth in a series examining driver fatigue in the Australian long-distance road transport industry. Thirty-seven long-haul truck drivers were measured on a routine 4,500-km round trip. Two types of driving operations were compared, single driving, involving a solo driver, and two-up driving, where a pair of drivers operate a truck continuously and alternate between work and rest. Two-up drivers reported higher levels of fatigue than single drivers overall and tended to show poorer levels of performance. However, this result appeared to reflect differential fatigue at the start of the trip. Both two-up and single drivers showed marked increase in fatigue across the first half of the trip, followed by a substantial recovery of alertness and performance provided that drivers had stationary overnight rest at mid trip or had shorter trips. Fatigue continued to increase on the second half of the trip for drivers who did longer trips without the benefit of a substantial night rest or who did not have access to on-board rest, that is, single drivers. The use of overnight rest, in combination with two-up driving, appeared to be the most successful strategy for managing fatigue across the trip.

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

The CMV Driver Fatigue and Alertness Study was the largest and most comprehensive over-the-road study of its kind ever conducted in North America. Its primary purposes were to establish measurable relationships between CMV driver activities and physiological and psychological indicators of fatigue and reduced alertness and to provide a scientifically valid basis to determine the potential for revisiting the 60-year-old HOS regulations. Work-related factors thought to influence the development of fatigue, loss of alertness, and degraded performance in CMV drivers were studied within an operational setting of real-life, revenue-generating trips. These included the amount of time spent driving during a work period; the number of consecutive days of driving; the time of day when driving took place; and schedule regularity. It was found that the strongest and most consistent factor influencing driver fatigue and alertness was time of day; drowsiness, as observed in video recordings of the driver's face, was markedly greater during night driving than during daytime driving. The number of hours of driving (time on task) was not a strong or consistent predictor of observed fatigue. Other study findings noted that the number of driving periods was not a strong or consistent fatigue predictor; that there was a low correlation between drivers' subjective self-ratings of alertness/sleepiness and concurrent objective performance measures; and that there was a large difference between the mount of sleep drivers reported as their "ideal" and the amount they obtained during principal sleep periods in the study setting. While there is no single solution to the fatigue problem, much can be done to address driver fatigue through a combination of innovative HOS regulation and enforcement, education, driver work scheduling, innovative fatigue management programs, driver screening, fitness for duty and alertness monitoring systems, and additional research. For the covering abstract of this conference, see IRRD number 872978.

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

Previous research has shown that night driving performance may be seriously affected by sleepiness. The present study compared daytime and nighttime performance of professional drivers on a simulated truck driving task. A secondary purpose was whether a nap or a rest pause would affect performance. Nine professional drivers participated in a counterbalanced design. The conditions were day driving (DAYDRIVE), night driving (NIGHTDRIVE), night driving with a 30-min rest (NIGHTREST), and night driving with a 30-min nap (NIGHTNAP). Each condition consisted of three consecutive 30-min periods. For the DAYDRIVE and NIGHTDRIVE, all periods were spent driving while the second period was either a rest pause or a nap for the other two conditions. Mean speed, standard deviation of speed, and standard deviation for lane position were recorded. Self ratings of sleepiness were obtained before and after each 30-min period. Reaction time tests and 10-min standardized EEG/EOG recordings were obtained before and after each condition. EEG/EOG recordings were obtained before and after each condition. EEGs/EOGs were also recorded continuously during driving. The effects on driving were small but significant: night driving was slower, with a higher variability of speed, and had higher variability of lane position. Subjective and EEG/EOG sleepiness were clearly higher during the night conditions. Reaction time performance was not significantly affected by conditions. Neither the nap nor the rest pause had any effect.

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

Questionnaire data concerning the frequency of prolonged driving, sleepiness-related problems while driving, and personal health status were analyzed from 567 professional drivers with 5 work descriptions. Of the drivers, 31% had been regularly driving more than 10 hr, 19% reported having dozed off at least twice while driving, and 8% reported a near-miss situation due to dozing off during the past 3 months. Sleepiness-related problems while driving appeared across all driver groups, including drivers transporting dangerous goods and bus drivers, and were strongly related to prolonged driving, sleep deficit and drivers' health status. The effects of the latter factors were interactive and cumulative: Frequent sleepiness-related problems occurred in more than one-half of the drivers with the combination of prolonged driving, sleep deficit, and lowered self-perceived health. The results give unreserved support for regulating driving hours and increase concern of the connection between professional drivers' health status and sleepiness-related problems while driving.

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

The goal of the Hanowski et al. (2000) study, which examined the impact of the individual differences of truck drivers on the occurrence of driving incidents, was to study fatigue experienced by short-haul truck drivers. Forty-two male short-haul drivers (mean age = 31) participated in the study. Drivers completed 2 weeks of Monday–Friday daytime driving on normal delivery routes that were within 100 mi of home. Their distribution of work consisted of driving (28%), loading/unloading (35%), other assignments (26%), waiting to unload (7%), eating (2%), resting (0.5%) and other activities (1.5%).

A number of measures were used to assess the fatigue, inattention, and drowsiness of the drivers, including analysis of a videotape of the 3-min interval preceding the start of a critical incident. An incident was defined as a control movement exceeding a threshold based on driver or analyst input. Analysts recorded eye transitions and the proportion of time that the driver's eyes were closed/nearly closed, or off the road, during these 3-min intervals.

The drivers' mean sleep was 6.43 hr per night (sleep log) and 5.31 hr based on the actiwatch. Drivers who showed evidence of fatigue and were involved in fatigue-related incidents had less sleep and of a poorer quality than drivers who did not show signs of fatigue. Twenty-one percent of the incidents implicated fatigue as a contributor based on observer assessments of drowsiness and the increase in proportion of time with eyes closed or nearly closed.

Over the 2-week period, there were 77 incidents (average 1.8 per driver) where the driver was judged to be at fault. With respect to individual differences, 10 of the 42 drivers were involved in 86% of the incidents. The younger and less experienced drivers were significantly more likely to be involved in critical incidents and exhibited higher on the job drowsiness.

The strength of this study is that it focuses on individual differences and it has strong face validity with respect to traffic safety issues. The main weakness from the perspective of our study is that it does not address recovery directly.

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

Driver fatigue is an important safety issue for long-haul truck drivers. To provide an efficient means of obtaining sleep, long-haul truck drivers often use tractors equipped with sleeper-berth units. Depending on the type of cargo and distances traveled, long-haul truck drivers either drive in teams or alone as single drivers. Team drivers, therefore, typically sleep in a moving truck whereas single drivers sleep in a stationary truck. It has been hypothesized that sleeping in a moving truck could adversely affect the sleep quality and, therefore, the alertness level of team drivers. A naturalistic data collection system was developed and installed in two Class 8 heavy trucks. This trigger-based system consisted of vehicle sensors and cameras that allowed the experimenters to obtain the driving performance and driver alertness data for analysis of fatigue. Fatigue was measured using both objective and subjective measures that were recorded before and after sleep and while driving. Fatigue and driving performance were compared for single versus team drivers to determine which driver type acquired the greatest sleep deficit during a trip. Results suggest that single drivers were more frequently involved in critical incidents while exhibiting extreme drowsiness than were team drivers by a factor of 4 to 1. These results are discussed in relation to the general safety of single versus team truck operations.

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

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

Minimizing driver fatigue among CMV drivers is a major safety issue in the United States. This paper examines the effects of potentially fatigue-inducing factors inherent in truck driving work and company safety management in explaining (1) drivers driving while fatigued, (2) the frequency of close calls due to fatigue, and (3) actual crashes among CMV drivers. Data for this study is derived from a survey of CMV drivers in 116 trucking firms, with all data being driver-reported. The relative roles of fatigue-inducing factors and safety management practices in explaining variation in fatigue, close calls, and crashes are reported, along with the roles of fatigue in affecting close calls and crashes via hierarchical regression. Findings indicate that fatigue-inducing factors inherent in driving work and safety practices accounted for appreciable variation in driving fatigue (R sq. = 0.42) and close calls (R sq. = 0.35), but not crash involvement. Driving while fatigued also accounted for incremental increases in the amount of variation in close calls, after considering inherent factors/safety practices.

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

This driving simulator study sought to assess truck driver fatigue or alertness as affected by non-driving, but on-duty activities, such as loading/unloading a vehicle. It also examined the effects of driver performance on extended HOS—14 hr on duty/10 hr off duty (12 hr daytime driving, 0700 to 2100). Researchers examined driver performance over a 15-day period. In addition, the amount of nonduty time (rest and recovery) needed to reestablish baseline fitness for duty was investigated.

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

The relationship between physical and mental fatigue is not well understood or well documented, a lapse that affects understanding of the interaction between loading and unloading activities and safe operation in the trucking industry. This experiment addresses the effects of loading and unloading on driving performance by measuring driving impairment in volunteer truck drivers operating a truck-driving simulator. Ten drivers participated, each for 17 days, including 2 driving weeks of 5 days with 14-hr duty cycles separated by two 58-hr rest periods. During one of the driving weeks, participants were given a significant hand-loading task, 3 hr of hand-loading pallets of boxes on 3 of 5 days; during the remaining week, only driving tasks were scheduled. Performance measurement focused on driver responses to planned and unplanned crash-likely challenges and vigilance tasks, supported by simulator-mediated driving indicators, such as lane-keeping performance. Measures of subjective drowsiness also were maintained. The effects of the loading and unloading task were mixed. There was an initial improvement in alertness, apparently because of the break in activity and a period of exercise; however, this effect wore off as the day progressed and may have contributed to a decrease in overall performance after 12 to 14 hr of duty.

O'Neill, T. R., Krueger, G. P., Van Hemel, S. B., and McGowan, A. L. (1999). "Effects of operating practices on commercial driver alertness." Rep. No. FHWA-MC-

99-140, Office of Motor Carrier and Highway Safety, Federal Highway Administration, Washington, D.C.

The goal of the O'Neill et al. (1999) study was to assess the effects of operating practices, namely schedule, loading and recovery, on alertness. Ten male CMV drivers participated in 1 week of driving operations in a simulator followed by 58 hr of recovery time. This was followed by another week of driving, 58 hr of recovery time and a final driving day to verify performance after recovery. Half of the drivers performed 3 days of loading in the first week (i.e., 2 × 1.5-hr sessions) and had no loading in the second week. The remaining drivers did the reverse (i.e., loaded in week 2). On loading days, drivers performed two 90-min loading/unloading sessions during the driving day, one in the morning, and one in the afternoon. The drivers worked 14 hr on duty (i.e., 12 hr driving plus scheduled breaks) beginning at 0700, followed by 10 hr off duty.

Measures of sleepiness, sleep length, psychomotor performance, and driving simulator performance were collected. The sleep measures included the Stanford sleepiness scale, self-alertness scales and wrist actigraphs (i.e., sleep length). Measures were collected using the PVT, which has been shown in previous studies to be very sensitive to sleepiness. The PVT is a 10-min period of reaction time performance where drivers respond as fast as possible to brief visual stimuli. Reaction time and lapses (reaction times exceeding 500 m/sec) are recorded. Driving simulator performance measures included lane position, speed maintenance, and shifting performance. Response probes (e.g., tire blowout, merge squeeze, fog, etc.) were used and driver response was evaluated by expert trainers on a three-point scale. Probes provided tests of driver vigilance, alertness, and response time.

Individual differences in performance in relation to age and height/weight were assessed. The age of the drivers was correlated with lane ($r = 0.508$, $p < 0.01$) and shifting performance ($r = -0.287$, $p < 0.01$). Drivers height/weight ratio (a surrogate measure for general fitness) was correlated with poorer lane performance ($r = -0.358$, $p < 0.001$) and shifting performance ($r = -0.428$, $p < 0.001$).

Overall, there was a gradual decline in driver response quality, as measured by response probes, with hours of driving. There were improvements after each break, regardless of whether it was a rest, meal, or loading activity. After 6.5 hr of driving, drivers were returned to starting levels of safety (as measured by response to probes) by a 45-min lunch break. The ability to maintain speed within posted limits and gear shifting performance deteriorated somewhat during the latter part of the driving day but there was no consistent linear relation to hours of driving.

There was an improvement in driver response to crash-likely simulated situations after the morning physical activity. However, gear shifting increased, indicating inefficiency in attention and co-ordination, and there was greater lane position variability after the morning loading session. The only effect of the afternoon loading session appeared to be an increase in cognitive errors, that is, lapses in vigilance leading to missed turns.

Over the driving week, there was a slight but statistically significant deterioration in subjective sleepiness, reaction time response, and measures of driving performance over each working day. However, driver response in crash-likely situations did not show cumulative deterioration. The schedule of 14 hr on duty/10 hr off duty (12 hr driving) for a 5-day week did not appear to produce significant cumulative fatigue over the 2-week testing period.

The drivers returned to baseline levels of reaction time, driving simulator performance, and alertness within 24 hr of recovery time after the end of a driving week as shown by sleep latency, reaction time testing, and driver rating of subjective sleepiness. However, it should be noted that drivers lived in an apartment during testing; therefore, sleep may not have been typical of normal conditions during recovery, where drivers must deal with family and social obligations which may result in reduced sleep.

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

The aim of the study presented was to assess the effects of lorry driver loading or unloading on subsequent driver alertness and to measure and document lorry drivers' performance on a 14 hr on (with 12 hr driving)/10 hr off daytime schedule coupled with a weekend recovery process over a 58-hr off-duty period between two successive weeks of simulated driving. Measurements of probe performance, cognitive errors, lane performance and gear performance were carried out. Sleep patterns, sleep latency and subjective sleepiness were also measured in order to assess the effect of the rest and recovery required to re-establish alertness and fitness for duty. For the covering abstract of the conference, see ITRD E204692.

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

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

This document is the final summary of a series of three reports of a project on the development of model work-rest schedules that have demonstrated effectiveness for managing driver fatigue in the long distance road transport industry. The purpose of these studies was to help the industry in designing work-rest schedules to provide additional flexibility for companies and drivers to meet their operational needs but also manage fatigue most effectively. The report provides an overview of the findings of each of the three studies. The first study developed a set of fatigue-sensitive performance measures and alcohol-equivalent standards for each of them. The results also demonstrated sleep deprivation of 17 hr or more produced decrements in performance capacity equivalent to the community-accepted standard of 0.05% BAC. They also showed that long distance drivers appeared to cope with the demands of sleep deprivation better than non-professional drivers. The second and third reports detailed the evaluation of four work-rest schedules, two of which complied with the current working hours regulations and two were alternative schedules that did not comply with the regulations. The evaluations were carried out on the road while drivers were doing their normal trips. The exception was one of the alternative compliance schedule evaluations which were done with professional long distance drivers in a simulation mode rather than on-road. The results of the regulated hours evaluations showed that as long as drivers were rested before their trips, the regulated regime produced increased fatigue and produced some performance decrements at the end of a work period between long 24-hr breaks. The level of effect was not significantly high however, relative to alcohol-equivalent standards. In contrast, the alternative compliance schedule evaluations demonstrated that it is possible to introduce flexibility in scheduling such as by extending the length of work periods, but only if an adequate balance is maintained between work and rest.

Williamson, A., Feyer, A., and Friswell, R. (1996). "The impact of work practices on fatigue in long distance truck drivers." ***Accident Analysis & Prevention,*** **Vol. 28, No. 6, 709–719.**

Both long- and short-haul drivers averaged approximately 7.5 hr of sleep per night, which is within normal limits for adults. However, in contrast to short-haul drivers who only obtained 3% of their sleep during on-duty periods, long-haul drivers obtained 44% of their sleep during on-duty periods. Short-haul drivers were more likely to consolidate their daily sleep into a single sleep period. As long-haul drivers obtained almost half of their daily sleep during work-shift hours (mainly sleep-berth time), it appears that they spend a significant portion of the work shift in a state of partial sleep deprivation, until the opportunity to obtain recovery sleep on duty presents itself.

There was no off-duty duration that guaranteed adequate sleep for the long- or short-haul drivers. As drivers likely use a substantial portion of their off-duty time to attend to personal business, off-duty time must be of sufficient duration to allow drivers to accomplish these tasks and to obtain sufficient sleep. This may be particularly important for long-haul drivers, who often did not sleep at all during off-duty periods.

The bulk of the first (main) daily sleep bouts for short-haul drivers were initiated between 2000 and 0200. Sleep bouts initiated at these times lasted longer (i.e., clustered between 6 and 10 hr) than sleep bouts initiated at other times of day. Several of the sleep bouts initiated between these times lasted longer than 12 hr.

Similar to the short-haul drivers, the majority of long-haul drivers' first sleep bouts were initiated between 2200 and 0359. However, long-haul drivers initiated their first sleep bouts more frequently during 0000 and 0359. The duration of long-haul drivers' first sleep bouts clustered between 6 and 10 hr in duration. Sleep bouts exceeding 10 hr in duration were uncommon and none exceeded 12 hr. Some sleep bouts were initiated in the early and late afternoon hours (1200 to 1959) and, unlike short-haul drivers, almost half of the first sleep bouts initiated during this time frame were longer than 4 hr in duration.

There were large day-to-day variations in total sleep time for drivers in both groups. Sleep times varied for some long- and short-haul drivers by up to 11.2 hr across the 20 study days for the long- and short-haul drivers. Other drivers maintained more consistent sleep/wake schedules. Some drivers showed a pattern that suggested chronic sleep restriction with intermittent bouts of extended recovery sleep. The authors believed that this suggested that although work-rest schedules can be devised to help minimize CMV driver sleep debt, optimal enhancement of driver alertness and performance will require additional and imaginative approaches.

The strength of this study is that all periods of sleep, not just those taken off duty, were recorded for a large group of CMV drivers over an extended period of time. The main limitation as far as this study is concerned is that the issue of recovery was not addressed specifically.

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

The purpose of this study was to assess the relationships between prevalence of driver drowsiness observed on a trip, length of prior principal sleep periods, and naps taken during the trip, based on 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 with the relatively high levels of drowsiness seen in the hour prior to napping. However, drowsiness remained substantially elevated for 2 hr after napping.

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

The purpose of this study was to assess the "recovery" effect of 0, 1, and 2 workdays off on driver fatigue and alertness. It was hypothesized that there would be some level of improvement in dependent measures of driver performance on trips following the time off. The study involved 25 of the 40 drivers who participated in the two Canadian observational conditions of the joint study by Canada and the United States known as DFAS. Field data were collected from 55 trips, in addition to those of the DFAS, and resulted in five new observational conditions that spanned a maximum of 8 workdays, nominally with 12 hr, 36 hr, and 48 hr of time off after the fourth workday. Three conditions included the 36-hr off-duty period, of which two had drivers do 4 more workdays following time off while the third had drivers do 1 more workday. Two conditions included 12 hr and 48 hr of time off and these had 1 more workday follow the time off. The data collection equipment and procedures were similar to those of the DFAS study and were described in detail in the final report issued on that project. Measures, which were identical to those used in the DFAS, included EEG, face video recordings, vehicle lane tracking, and computerized surrogate performance tests. Because of the smaller number of drivers who participated in this "recovery" study by comparison with the DFAS, the statistical tests did not have the same power to detect effects. For 1 workday off (i.e., 36 hr), there was (1) no objective evidence of driver recovery; (2) some improvement in driver 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 2 workdays off (i.e., 48 hr) 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.

Wylie, C.D., Shultz, T., Miller, J.C., Mitler, M.M., and Mackie, R.R. "Commercial motor vehicle driver fatigue and alertness study."

This is the full final report on the largest and most comprehensive over-the-road study of CMV driver fatigue ever conducted in North America. The data collection involved 80 drivers in the United States and Canada who were monitored over a period of 16 weeks. A number of work-related factors thought to influence the development of fatigue, loss of alertness, and degraded performance in CMV drivers was studied within an operational setting of real-life, revenue-generating trips. These included the amount of time spent driving during a work period, the number of consecutive days of driving, the time of day when driving took place, and schedule regularity. In Chapter 1, the reader is provided with the background to the study as well as the study's overall objectives and the approach used in their attainment. Chapter 2 presents a detailed literature review on driver fatigue and its measurement, as well as the involvement of fatigue in crashes that was conducted in preparation for the study and considered in the formulation of the study's own conclusions and recommendations. Chapter 3 presents the study methodology and data collections methods. Chapter 4 presents the detailed results. Chapter 5 provides an overview of the results and the study's conclusions and recommendations. For the amount of sleep and the 4 to 5 days of driving observed for each driver in this study, it was found that the strongest and most consistent factor influencing driver fatigue and alertness was time of day; drowsiness, as observed in video recordings of the driver's face, was markedly greater during night driving than during daytime driving. The number of hours of driving (time on task) and cumulative number of days were not strong or consistent predictors of observed fatigue. Numerous other findings are provided relating to scientific methodologies and fatigue countermeasure concepts.

SECONDARY SOURCES

Abrams, C., Schultz, T., and Wylie, C.D. (1997). "Commercial motor vehicle driver fatigue, alertness, and countermeasures survey." U.S. Department of Transportation, Federal Highway Administration. No. FHWA-MC-99-067.

Akerstedt et al. (2000). "Sleepiness and days of recovery."

Anund, A., Kecklund, G., and Larsson, J. (2002). "Fatigued drivers in focus." Swedish National Road Administration.

Apparies et al. (1998). "A psychophysiological investigation of the effects of driving longer-combination vehicles."

American Trucking Associations, Inc.
SB: TRB-TRIS.
TI: Eye-Activity Measures of Fatigue and Napping as a Fatigue Countermeasure.
SO: 1999/01. 9709-9802 pp.164 (Figs., Tabs., Refs., 11 App.)
PY: 1999.
RN: Report Number: FHWA-MC-99-028; Report Number: Final Report; Contract/Grant Number: DTFH61-96-00022.
AB: This study investigated (1) the potential use of an eye tracking system for detecting reduced driver alertness and (2) the impact of prophylactic napping on driver performance and alertness. The study used traditional behavioral and physiological measures of alertness. In addition, an unobtrusive eye tracker attached to the simulator structure was used to measure eye and eyelid behavior. The results showed clear time-of-day and time on task effects for the following eye closure measures: partial closures during fixations, speed of slow eyelid closure (SEC), blink duration, and blink frequency. Eye closures during fixations exhibited the following alertness monitoring characteristics: (1) the cyclic phases of a driver experiencing brief lapses of alertness and recovery, (2) a continuous decline ultimately leading to an off-road simulator crash, (3) an early warning potential of 10 min or more, (4) a dramatic decline in the measure beginning 2 to 3 min

before an off-road simulator crash. SEC events and blink duration showed sustained increases with time on task and time of day. A preliminary algorithm for detecting level of alertness was developed. This algorithm uses the eye closure measure in a way that includes partial eye closures during fixations, blink frequency, blink duration, and speed of eye closure effects. The 3-hr afternoon nap increased the subjects' nighttime alertness and improved driving performance. Beneficial effects of the afternoon nap on nighttime driving performance included significantly fewer crashes, shorter run completion times, and smaller standard deviations of lane position. The results provide evidence that the 3-hr afternoon nap was effective in reducing sleepiness levels during the following night and suggest that prophylactic naps may be more beneficial than recuperative naps during all-night driving situations.
AN: 00763223

Balkin et al. (2000). "Effects of sleep schedules on commercial motor vehicle driver performance."

Brice, C. and Smith, A.
SB: IRRD-OECD.
TI: Caffeine and fatigue: mental performance and driving.
SO: International Conference on Fatigue and Transportation, 4th, 2000, Fremantle, Western Australia. 2000. 32 p. (12 Refs.)
PY: 2000.
AB: The majority of studies to date have investigated the behavioural effects of caffeine in laboratory experiments using artificial tasks. It is now important to ask whether similar effects are observed in simulations of real-life activities, such as driving, and to consider whether consumption of caffeine can reduce fatigue over long time periods, for instance over the working day. A number of studies show that caffeine can improve driving performance of fatigued drivers. In the current study 3mg/kg caffeine was found to improve steering accuracy in drivers carrying out a 1-hr simulated drive. In addition, measures of mood and performance of artificial tasks were recorded in this study and these also showed the benefits of consuming caffeine. These findings suggest that changes in the laboratory may reflect a general benefit of caffeine that is also observed in real-1ife situations. Further evidence from Smith examining the effects of caffeine on performance efficiency over the working day has shown the benefits of caffeine consumption on measures of sustained attention and alertness. Furthermore, this study also provided evidence to suggest that caffeine is often consumed when alertness is low to maximize alertness and performance efficiency. The implications of these findings in terms of road safety are also considered. (a) For the covering entry of this conference, see ITRD abstract no. E204477.
AN: E204481

Brill, J.C., Hancock, P.A., and Gilson, R.D.
SB: TRB-TRIS.
TI: Driver Fatigue: Is Something Missing?
CA: University of Iowa, Iowa City, IA.
SO: Conference Title: Driving Assessment 2003: The Second International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Location: Park City, Utah. Sponsored by: FHWA; FMCSA; Honda R&D Americas, Inc.; Motorola; NHTSA; Univ. of Iowa; Nissan Technical Center North America; Univ. of Minnesota; Virginia Tech; Seeing Machines—Australia; UMTRI; TTI; Univ. of Leeds, UK; Human Factors and Ergonomics Society; and TRB. Held: 20030721-20030724. 2003. pp. 138–142 (Refs.)
PY: 2003.
AB: Drowsiness and fatigue are serious problems in all transportation systems. One persistent issue is the lack of an agreed definition of these respective energetic states. This paper reviews the theoretical approaches (cognitive versus physiological) framing the driver fatigue problem. Known contributing factors to drowsiness include sleep debt, circadian rhythm, and shift work. However, it is also suggested that certain inherent physiological reactions engaged in responses to motion itself represent a previously unrecognized but significant source of fatigue. The impact of this factor is confirmed through comparisons of studies that either have or have not included prolonged motion.
AN: 00970486

Brown, W.J.
SB: IRRD-OECD.
TI: Interaction Between Extended Duty Hours and Circadian Rhythms: Consequent Effects on Long-Haul Driver Alertness and Performance.
SO: Proceedings of the 29th Annual Meeting of the Canadian Transportation Research Forum: Going the Distance, Victoria, British Columbia, May 15–18, 1994. pp. 532–547.
PY: 1994.
AB: A major Canadian rail disaster in 1986 resulted in the loss of 26 lives and $30 million in property damage. The investigation demonstrated that severe disruptions to the engineer's circadian rhythms caused by erratic schedules and extended duty hours impaired engineer performance resulting in the rail disaster. This finding is supported by GAO studies (1992, 1993) on rail safety which showed similar results. The purpose of the present study is to determine whether the work-rest patterns of long-haul truck drivers are similar to those of train engineers and the consequences for safety in the trucking industry. For the covering abstract of this conference, see IRRD number 863285.

Brown, J., Horberry, T., and Anderson, J.
SB: IRRD-OECD.
TI: Investigation of the effects of driver distraction.
SO: Road Safety Research, Policing and Education Conference, 2003, Sydney, New South Wales, Australia. 2003. 97-105 (Vol. 2) (38 Refs.)
PY: 2003.

RN: 0 73105 395 8.
AB: The MUARC advanced car driving simulator was used to undertake a study that examined the effects of distraction upon driving performance for drivers in three age groups. There were two in-car distractions: operating the car audio system and conducting a simulated hands-free mobile phone conversation. The study employed a hazard perception task, whereby the effects of distraction were assessed in terms of drivers' reactions to pedestrians and other hazards in the roadway. Older drivers (over 60 years old) drove more slowly when they were distracted by the audio system and in the complex driving environment. Younger people (18 to 25 years old) maintained a more constant speed compared with middle aged (30 to 45 years old) and older drivers (over 60). Fatigue caused by loss of sleep the night before the test or by the driving task itself did not affect driver performance. The authors concluded that the in-vehicle tasks of interacting with the audio system and conducting a simulated hands-free mobile phone conversation do impair several aspects of driving performance. (a) For the covering entry of this conference, see ITRD abstract no. E210298.
AN: E210429

Charlton, S.G. and Isler, R.B.
SB: IRRD-OECD.
TI: Road Safety Research at Waikato University in New Zealand.
SO: International Conference on Traffic and Transport Psychology—ICTTP 2000, Held 4–7 September 2000, Berne, Switzerland—Keynotes, Symposia, Thematic Sessions, Workshops, Posters, List of Participants and Word Viewer—CD ROM. 2001. (12 Refs.)
PY: 2001.
AB: The University of Waikato's Traffic and Road Safety Research Group (TARS) was founded in 1993. Since then, the capabilities and research output of TARS have grown steadily, developing good relationships with industry, governmental, and regulatory end users in the transport and road safety communities. Currently, in a government-funded project, TARS researchers are employing advanced driving simulator techniques and instrumented vehicles in order to develop human factors models characterizing driving performance and decisionmaking in various driving situations. Fatigue and Fitness for Duty in New Zealand Truck Drivers is another current project funded by Road Safety Trust. Using a portable driving simulator installed in a caravan, volunteer truck drivers are asked to complete a brief survey and take a diagnostic driving fatigue test at rest stops, depots, and cargo terminals throughout the day and night. Another TARS project involves teaching novice drivers appropriate eye scanning while negotiating curves. By using sophisticated eye tracking equipment, TARS researchers can detect and correct inappropriate looking behaviours in a safe environment of a driving simulator and in real traffic situations. For the covering abstract, see ITRD E113725.
AN: E114139

DeValck, E. and Cluydts, R.
SB: TRB-TRIS.
TI: Slow-Release Caffeine as a Countermeasure to Driver Sleepiness Induced by Partial Sleep Deprivation.
SO: Journal of Sleep Research. 2001. 10(3) pp. 203–209 (Refs.)
PY: 2001.
AB: This paper studied the effect of partial sleep deprivation (PSD) on driving abilities, as measured with a driving simulator, and the value of slow-release caffeine as a countermeasure to the expected performance decrements. Twelve subjects (20 to 25 years old) underwent four experimental conditions: 4.5 or 7.5 hr time in bed, both with 300 mg slow-release caffeine or placebo. Driving performance was measured twice by a 45-min driving task on a simulator. Subjective sleepiness/alertness and mood were assessed 4 times by the Stanford Sleepiness Scale and the Profile of Mood States. After 4.5 hr, as compared with 7.5 hr time in bed, drifting and speed deviation were higher, but only the effect on the first variable reached significance. In the placebo condition at 13 hr, accident liability increased after PSD. Subjective sleepiness was higher in the 4.5 hr time in bed group. Findings suggest that a lack of sleep can lead to a significant driving performance impairment, and that slow-release caffeine can serve as a valuable countermeasure to the performance decrements.
AN: 00932761

Desmond, P.A., Hancock, P.A., and Monette, J.L.
SB: TRB-TRIS.
TI: Fatigue and Automation-Induced Impairments in Simulated Driving Performance.
SO: Transportation Research Record. 1998. (1628) pp. 8–14 (4 Fig., 24 Ref.)
PY: 1998.
RN: 0309064732.
AB: A driving simulator study investigated the effect of automation of the driving task on performance under fatiguing driving conditions. In the study, drivers performed both a manual drive, in which they had full control over the driving task, and an automated drive, in which the vehicle was controlled by an automated driving system. During both drives, three perturbing events occurred at early, intermediate, and late phases in the drives: in the automated drive, a failure in automation caused the vehicle to drift toward the edge of the road; in the manual drive, wind gusts resulted in the vehicle drifting in the same direction and magnitude as the "drifts" in the automated drive. Following automation failure, drivers were forced to control the vehicle manually until the system became operational again. Drivers' lateral control of the vehicle was assessed during three phases of manual control in both drives. The results indicate that performance recovery was better when drivers had full manual control of the vehicle throughout the drive, rather than when drivers were forced to drive manually following automation failure. Drivers also experienced increased tiredness, and physical and perceptual fatigue symptoms following both drives. The findings have

important implications for the design of intelligent transportation systems. Systems that reduce the driver's perceptions of task demands of driving are likely to undermobilize effort in fatigued drivers. Thus, the results strongly support the contention that human-centered transportation strategies, in which the driver is involved in the driving task, are superior to total automation.
AN: 00755015

Desmond, P. "Efficiency of vehicle-based data to predict lane departure arising from loss of alertness due to fatigue." (1996). Proceedings of the 40th Annual Conference of the Association for the Advancement of Automotive Medicine. October 7–9, 363–76.

Fairclough, S.H. and Graham, R.
SB: TRB-TRIS.
TI: Impairment of Driving Performance Caused by Sleep Deprivation or Alcohol: A Comparative Study.
SO: Human Factors. 1999/03. 41(1) pp. 118–128 (2 Fig., 2 Tab., 27 Ref.)
PY: 1999.
RN: Contract/Grant Number: TR 1047.
AB: This study assessed the relative impact of partial sleep deprivation (restriction to 4 hr of sleep before testing) and full sleep deprivation (no sleep on the night before testing) on 2 hr of simulated driving, compared with an alcohol treatment (mean BAC = 0.07%). Data were collected from 64 male participants on the primary driving task, psychophysiology (0.1 Hz heart rate variability), and subjective self-assessment. Results revealed that the full sleep deprivation group and alcohol group exhibited a safety-critical decline in lane-keeping performance. The partial sleep deprivation group exhibited only noncritical alterations in primary task performance. Both sleep-deprived groups were characterized by subjective discomfort and an awareness of reduced performance capability. These subjective symptoms were not perceived by the alcohol group. The findings are discussed with reference to the development of systems for the online diagnosis of driver fatigue. Potential applications of this research include the formulation of performance criteria to be encompassed within a driver impairment monitoring system.
AN: 00765019

Fairclough, S.H. and van Winsum, W.
SB: TRB-TRIS.
TI: The Influence of Impairment Feedback on Driver Behavior: A Simulator Study.
SO: Transportation Human Factors. 2000. 2(3) pp. 229–246 (4 Fig., 4 Tab., 32 Ref..)
PY: 2000.
AB: A variety of impairment-detection technologies have been developed as potential countermeasures to the degradation of driving performance due to the influence of fatigue, alcohol, drugs, emotional stress, and distraction. The majority of the research has focused on the development of technology, that is, the construction of sensitive and reliable sensor apparatus or associated algorithms, or both. Few studies have been concerned with those driver-system interactions issues underlying this category of technology. Eighteen male participants took part in a repeated measure design in which they performed simulated journeys with and without impairment feedback. The diagnosis and assessment of impairment were based on the quality of vehicular control. Impairment feedback was presented in the form of two interface designs, one providing three levels of feedback and another capable of nine levels of feedback. The results indicated that impairment feedback counteracts the characteristic degradation of driving performance due to time on task with respect to vehicular control. However, the presence of feedback (in either form) failed to influence participants' decision to discontinue the journey. In addition, impairment feedback failed to significantly influence psychophysiological effort, subjective fatigue, or subjective mental workload. The authors also discuss the implications of these finding for future research and development.
AN: 00812272

Fatigue Expert Group.
SB: IRRD-OECD.
TI: Fatigue Expert Group: options for regulatory approach to fatigue in drivers of heavy vehicles in Australia and New Zealand.
SO: Report. 2001/02. (CR 202) 70 p.
PY: 2001.
RN: 0-642-54478-6.
AB: This report was commissioned jointly by the National Road Transport Commission of Australia, the Australian Transport Safety Bureau, and the New Zealand Land Transport Safety Authority. The fatigue expert group comprised leading Australian and New Zealand experts in sleep, shift work, and road safety who collaborated with the participating agencies and industry representatives to construct a set of evidence-based design principles for future fatigue regulatory options. The group considered that the management of driver fatigue is not a matter for operators and drivers alone, and emphasised the requirements and practices of others in the transport supply chain. The chain of responsibility provisions in road transport legislation are designed to highlight that on-road performance is closely related to the decisions made by customers, consignors and loaders. The expert group was conscious of the need to provide a flexible and practicable framework in which fatigue could be actively managed by all those who are part of the supply chain. The group agreed on the following principles for designing better regulations: provision for minimum sleep periods, the opportunity for sleep and time of day influences; taking account of the cumulative nature of fatigue and sleep loss; taking account of the effect of night work on driving performance and both quality and quantify of sleep; taking account of duration of working time; and provision of short breaks within working time.

The group considered that any policy approach to the management of fatigue in drivers of heavy vehicles must address these factors and proposed a possible model for the application of these design principles.
AN: E204309

Filiatrault, D.D., Vavrik, J., Kuzeljevic, B., and Cooper, P.J.
SB: TRB-TRIS.
TI: The Effect of Rest-Schedule Orientation on Sleep Quality of Commercial Drivers.
SO: Conference Title: 43rd Annual Proceedings of the Association for the Advancement of Automotive Medicine. Location: Barcelona (Sitges), Spain. Sponsored by: Association for the Advancement of Automotive Medicine. Held: 19990920–19990921. Association for the Advancement of Auto Medicine Proc. 1999. pp. 329–343 (1 Fig., 7 Tab., Refs.)
PY: 1999.
AB: A study was conducted to examine the relationship between sleep quality and how CMV drivers balanced conflict when the need to rest interfered with their ability to maintain tight delivery schedules. Face-to-face interviews were conducted with 188 CMV drivers to collect physiological data and self-reported measures. Multivariate linear regression models were developed to analyze relationships between sleep quality, sleep quantity, symptoms of obstructive sleep apnea, and how schedule-based priorities were established. A significant correlation was found between sleep quality and how preference was given by CMV drivers, when symptoms of fatigue were detected, to balance conflict between the need to rest and the real or perceived duty to comply with externally-imposed schedule demands.
AN: 00784208

Frith, W.J.
SB: IRRD-OECD.
TI: A Case Control Study of Heavy Vehicle Drivers' Working Time and Safety.
SO: 17TH ARRB Conference, Gold Coast, Queensland, 15–19 August 1994; Proceedings; Volume 17, Part 5. 1994. pp. 17–30 (13 Refs.)
PY: 1994.
AB: In New Zealand, heavy vehicle drivers carry log books in which details of their driving hours must be recorded. It was decided to use this information to carry out a study on the risk of crash with respect to driving hours and other time intervals related to the drivers' working lives. In the study, a case group of heavy vehicles involved in crashes (for which details of drivers' hours were known from their log books) was compared with a control group of vehicles. The control group was selected by police going to the scenes of crashes on an anniversary of the crash, at the same time of day as the crash, and stopping a heavy vehicle. Where possible a vehicle was selected which was travelling in the same direction as the crash vehicle and which was of a similar configuration. Evidence was found of an increased crash risk in those cases where driving exceeded 8 hr since the driver's last compulsory 10-hr off-duty period (as recorded in the log book). There were no other significant differences between the two groups with respect to other time intervals related to driving habits. There was a significant difference between the age distribution of the crash and control drivers with the crash drivers generally being younger. (a) For the covering abstract of this conference, see IRRD abstract no. 861222.
AN: 861294

Gale, A.G.(Ed.), Desmond, P.A., and Matthews, G.
SB: IRRD-OECD.
TI: The effects of motivational and perceptual-based interventions on fatigue-related decrements in simulated driving performance.
SO: Vision in Vehicles—VII. 1999. pp. 149–56 (8 Refs.)
PY: 1999.
RN: 0-08-043671-4.
AB: The aim of this study is to explore the differing predictions which may be derived from motivational and feedback hypotheses concerning fatigue-related decrements. The study explores these hypotheses by examining the effects of three types of interventions on drivers' lateral control: motivational, when subjects were presented with instruction that driving skill was being measured; enhanced feedback, when the simulated road surface changed colour if the car deviated from a central lane; and reduced feedback, when the simulated environment was presented as being the same colour as the road surface. Driving performance was measured under conditions of task-induced fatigue and on a control drive. The findings of the study showed that the control drive produced greater subjective fatigue than the fatigue drive itself, principally categorised as heightened boredom or apathy. The findings have implications for in-vehicle countermeasures to fatigue. (a) For the covering abstract, see ITRD E106152.
AN: E106168

Gale, A.G.(Ed.), Desmond, P.A. and Matthews, G.
SB: IRRD-OECD.
TI: Task-induced fatigue effects on simulated driving performance.
SO: Vision in Vehicles—VI. 1998. pp. 115–22 (12 Refs.)
PY: 1998.
RN: 0-08-43579-3.
AB: Resource theories and dynamic models of stress and sustained performance make conflicting predictions concerning the nature of the interaction between fatigue effects and task demands. Resource theories suggest that fatigue may deplete attentional resources, so that detrimental effects of fatigue on performance are exacerbated when the task is highly demanding. Matthews et al. (1996) suggest that a variety of stress states may disrupt matching of effort to task demands. If so, the fatigued driver may fail to mobilize effort effectively when the task appears undemanding. These two conflicting hypotheses were tested with the Aston Driver Simulator, a

microcomputer-controlled fixed-base simulator of moderate fidelity (see Matthews et al., 1996). In the present study, drivers performed both a fatiguing drive, in the first part of which a fatigue-induction procedure was added to the primary task of driving and a control drive with no additional fatigue-induction procedure. The effects of the fatigue manipulation on drivers' subjective states were assessed by a selection of subjective measures. For the covering abstract, see IRRD E102207.
AN: E102219

Prepared by Margaret Gordetsky.
SB: TRB-TRIS.
TI: Australian Studies Urge Flexible Driving Hours, Fixed Rest Periods.
SO: Transport Topics. 2001/03/19.
PY: 2001.
AB: Subtitle: Several Agencies Work on Fatigue-Fighting Policies.
AN: 00907369.

Gouin, V., Sagot, J.C. and Roussel, B.
SB: TRB-TRIS.
TI: Train Drivers' Fatigue During a Seven Hour Daytime Trip. In: Engineering Psychology and Cognitive Ergonomics. Aerospace and Transportation Systems.
CA: Ashgate Publishing Company, 131 Main Street, Burlington, VT.
SO: Conference Title: Third International Conference on Engineering Psychology and Cognitive Ergonomics. Aerospace and Transportation Systems. Location: Edinburgh, Scotland. Sponsored by: College of Aeronautics, Cranfield University. Held: 20001025–20001027. 2001. pp. 455–462 (4 Fig., Refs.)
PY: 2001.
RN: 0754613372.
AB: A continuous daytime driving period of 7 hr is common on French railways. A question often arises of the fatigue felt by drivers during such long driving times. Described in this paper is the methodology and given is a part of the results obtained during the Paris-Nice line, 6 hr 40 min of driving. The results focus on the psychological and behavioral aspects of the high speed, long driving task. No feeling of fatigue is shown as expressed by the drivers in subjective evaluation. Yet, the behavioral adjustments observed clearly indicate that the task took its toll. The train drivers' experience makes these adjustments possible.
AN: 00934408

Grunstein, R.R., Desai, A., Marks, G., Barlett, D., and Jankelson, D. "The interaction of mild obstructive sleep apnea, sleep deprivation, and circadian factors in driving risk." (2003). Road Safety Research, Policing and Education Conference, pp. 309–14 (Vol. 2) (5 Refs.)

Grunstein, R.R., Desai, A., Marks, G., Williams, A. and Barlett, D. (Woolcock Institute of Medical Research), and Jankelson, D. (St. Vincent's Clinic. Sleep Disorders Service)
SB: IRRD-OECD.
TI: The interaction of mild obstructive sleep apnea, sleep deprivation, and circadian factors in driving risk.
SO: Road Safety Research, Policing and Education Conference, 2003, Sydney, New South Wales, Australia. 2003. pp. 309–14 (Vol. 2) (5 Refs.)
PY: 2003.
RN: 0 73105 395 8.
AB: Obstructive sleep apnea (OSA) is a breathing disorder occurring in sleep, with important nighttime and daytime consequences. This study primarily sought to examine the added effect of fatigue promoting factors (sleep deprivation and time of day) on driving performance and cognitive function in mild OSA patients. Currently licensed male drivers (25 to 55 years old) underwent overnight polysomnography to identify the presence of mild OSA. Clear effects of sleep deprivation and time of day were found in all subjects but no significant group differences were found. Although mild OSA drivers were not different to the control group in their response to sleep deprivation or time of day influences, they were less aware of their impairment due to sleep deprivation. In one reaction time task, mild OSA drivers showed greater impairment than controls at certain times of the day after sleep deprivation. (a) For the covering entry of this conference, see ITRD abstract no. E210298.
AN: E210461

Haile, J.
SB: IRRD-OECD.
TI: A visit to Canadian Pacific Railways, 25–27 September 1995.
SO: Fatigue and Accidents: A Multi-Modal Approach. Proceedings of a Conference Organised by the Parliamentary Advisory Council for Transport Safety, Held March 1996, London, UK. 1996/03. pp. 99–102.
PY: 1996.
AB: The CANALERT project, a study of Canadian freight train drivers and their working hours, is described. Forty volunteer drivers were known to be on duty for up to 18 hr (usually 12 to 16 hr) with up to a 4-hr rest period mid shift. A 1 day on, 1 day off shift pattern was worked. There was also a maximum driving mileage per month. The study was undertaken with the removal of the previous blame culture surrounding individuals who had fallen asleep. These drivers were monitored using sleep tracking diaries, 24-hr activity monitoring, questionnaires, and human physiology monitoring. New measures tested included rostering to the individual's body clock by restricting return journey start times, training staff and families in the importance of the body clock, improvement of the bunk house facilities, allowing short 30-min naps during excessively long shifts, and allowing drivers to listen to music through headphones. The drivers said

they felt fitter after the implementation of the new measures. The relevance of the study to UK rail services is discussed. For the covering abstract, see ITRD E111306.
AN: E111310

Hancock, P.A. (Ed.), Desmond, P.A. (Ed.), Brookhuis, K.A., and DeWaard, D.
SB: IRRD-OECD.
TI: Assessment of drivers' workload: performance and subjective and physiological indexes.
SO: Stress, Workload and Fatigue. 2001. pp. 321–33.
PY: 2001.
RN: 0-8058-3178-9.
AB: There are many reasons that the measurement of drivers' mental workload has great interest these days and will increasingly enjoy this status in the near future. Accidents are numerous, seemingly ineradicable, very costly, and largely attributable to the human factor. Human errors in the sense of imperfect perception, insufficient attention, and inadequate information processing are the major causes of the bulk of the accidents on the road (Smiley and Brookhuis 1987, Treat et al. 1977). Although both low and high mental workloads are undoubtedly basic conditions for these errors, an exact relation between mental workload and accident causation is not easily established or easily measured in practice. The measurement of drivers' mental workload offers opportunities and pitfalls, as illustrated in De Waard's model of driver performance, demands, and mental workload (De Waard 1996). Although stability of primary measures of driving performance over time is what the drivers' goals are, the conditions are variable and sometimes strongly demanding and require effort in variable "amounts" that at times are beyond capacity. The accident proneness that follows such conditions is the (for the time being irrefutable) rationale for the measurement of drivers' mental workload. For the covering abstract, see ITRD E108674.
AN: E108678

Hartley, L.R. (Ed.) and Richardson, J.H.
SB: IRRD-OECD.
TI: The Development of a Driver Alertness Monitoring System.
SO: Fatigue and Driving. Driver Impairment, Driver Fatigue and Driving Simulation. 1995. pp. 219–29 (7 Refs.)
PY: 1995.
RN: 0-7484-0262-4.
AB: This chapter describes the monitoring of driver alertness as part of a project to develop a reliable in-vehicle warning system which could be incorporated into an intelligent vehicle highway system. Driver fatigue was measured in a series of trials. The first used a laboratory simulator to collect psychophysiological data from drivers experiencing levels of fatigue that could not be induced on public roads. The second trial involved a real driving task on a private airfield with sleep-deprived drivers. The final trial used a 150-mi motorway loop without sleep deprivation. Graphs are presented which show changes in drowsiness with time. For the covering abstract, see IRRD 876074.
AN: 876092

Hartley, L.R.
SB: TRB-TRIS.
TI: Beyond One Size Fits All Hours of Service Regulations.
CA: American Trucking Associations, Inc, Alexandria, VA.
SO: Conference Title: Managing Fatigue in Transportation. Location: Tampa, Florida. Sponsored by: American Trucking Associations, Association of American Railroads, Federal Highway Administration, Federal Railroad Administration, National Highway Traffic Safety Administration, and National Transportation Safety Board. Held: 19970429–19970430. 1998. pp. 9–27 (9 Tab., Refs.)
PY: 1998.
RN: 0865875162.
AB: Increasing attention, both nationally and internationally, is being paid to the management of fatigue among all classes of drivers but especially among truck and bus drivers. This paper is divided into two parts. The first part describes research into the question of whether the introduction of driving and related working hours regulations to Western Australia (WA) would be beneficial. To do so, research considered the impact of the proposed regulations on the WA industry; the success of enforcing the regulations in other states; the impact of fatigue on drivers in WA versus the states regulating driving hours; and the effectiveness of self regulation in WA as compared with enforcement in other states. It was concluded that there is no evidence that the introduction of prescriptive driving hours into WA would benefit the community, and quite possibly might worsen the problem of fatigue. The second part of the paper describes the WA Government response to the research.
AN: 00789167

Hartley, L.
SB: IRRD-OECD.
TI: Australian initiatives in managing fatigue in transportation.
SO: Insurance Commission of Western Australia Conference on Road Safety, 1999, Perth, Western Australia. 1999/11. pp. 124–39 (5 Refs.)
PY: 1999.
AB: In most developed jurisdictions, fatigue has been addressed by restricting HOS and mandating time off work. In most of Australia, under the Truck Driving Hours Regulations, a driver cannot drive more than 12 hr or work more than 14 hr in each 24-hr period, with minimum rest requirements during that period. No more than 72 hr driving or working is possible in a 7-day period, and one continuous 24-hr rest break must be taken away from the truck during this time. There are a number of criticisms of this approach including its lack of flexibility, failure to consider the circadian rhythms of drivers, poor compliance because of the absence of incentives to do

so, poor enforcement because of the difficulties of doing so, and rigid restriction on HOS may prevent drivers reaching better rest facilities only a short distance away. Improved management of fatigue must address these issues. Two Australian alternatives to the traditional HOS regime are described. (a) For the covering entry of this conference, see ITRD abstract no. E205827.
AN: E205836

Haworth, N.
SB: IRRD-OECD.
TI: Does Regulating Driving Hours Improve Safety?
SO: International Conference on Fatigue and Transportation, 3rd, 1998, Fremantle, Western Australia. 1998. 10 p. (17 Refs.)
PY: 1998.
RN: 0-86905-607-7.
AB: Many of those who argue for regulations governing driving hours do so on the basis of ensuring safety standards. The underlying assumption is that limiting the hours of driving per day and per session results in drivers who are more alert and are, therefore, involved in fewer crashes. While this assumption has mass appeal, there is little rigorous support for it. This paper examines the difficulties involved in assessing whether regulating driving hours improves safety. The issues and drawbacks involved in comparing the safety performance of road transport in currently regulated and unregulated areas are discussed. The characteristics and information requirements of a model which could be developed to test the safety (and cost) implications of having no driving hours regulations or different types of regulations are proposed. (a) For the covering entry of this conference, see IRRD abstract no. 895120.
AN: 895129

Horne, J.A. and Reyner, L.A.
SB: IRRD-OECD.
TI: Falling Asleep at the Wheel.
SO: TRL Report. 1995. (168) 26 p.
PY: 1995.
AB: Certain practical measures to counteract sleepiness under monotonous driving conditions, have been evaluated. Three treatments were given separately during a 30-min rest period between two, 1-hr monotonous drives: a placebo (decaffeinated coffee), a nap (less than 15 min), and 150-mg caffeine (in decaffeinated coffee). Ten subjects (experienced drivers) underwent all conditions in a balanced design. Sleep was restricted to 5 hr the night before each treatment condition. An interactive and instrumented driving simulator emulated monotonous driving. Subjects drove between 14:00h and 16:30h. Major and minor lane deviations were identified. Subjects reported their subjective alert/sleepiness levels, and recordings were made of brain (EEG) and eye activities (EOGs). Video records showed facial/postural changes. Both caffeine and a nap significantly reduced driving impairments, subjective sleepiness, and EEG activities indicative of drowsiness; these effects lasted for the 1 hr duration of driving after treatment. The findings with caffeine were consistent across subjects, whereas those for nap were less so, depending on the ability to nap (most subjects napped). Eye movements (e.g. eye rolling) were unreliable in determining sleepiness and inferior to the other measures. Changes in driving performance and EEG were closely linked, but there was a small time lag between the two. Subjects were aware of their deteriorating EEG state of alertness almost “on line.” Self-knowledge is a good guide to real sleepiness, but subjects may not realise that sleepiness portends sleep, which may descend rapidly thereafter. If one has to drive whilst sleepy, then a break with coffee or a nap can be beneficial, but only for a while.

Hurwitz, J.B.
SB: IRRD-OECD.
TI: Individual differences in driver risk acceptance during sleep deprivation.
SO: International Conference on Traffic and Transport Psychology—ICTTP 2000, Held 4–7 September 2000, Berne, Switzerland—Keynotes, Symposia, Thematic Sessions, Workshops, Posters, List of Participants and Word Viewer—CD ROM. 2001. (26 Refs.)
PY: 2001.
AB: This paper investigates the role of decisional processes in fatigued drivers. Test subjects were asked to perform a simple computer-based driving task during a period of sleep deprivation. Individual performance was simulated using a mathematical model of driver risk acceptance. Drivers accept risk by initiating manoeuvres before having sufficient information to determine the consequences. The results suggested that the modeling used could be employed to detect changes in risk taking resulting from sleep loss, and could therefore be useful in developing in-car driver support systems to include countermeasures. For the covering abstract, see ITRD E113725.
AN: E113860

Janssen, W.
SB: IRRD-OECD.
TI: How to improve a safe and sustainable driver behaviour—driver’s fatigue?
SO: Safe and Sustainable Transport. A Matter of Quality Assurance. 2003. pp. 107–18 (10 Refs.)
PY: 2003.
RN: 92-821-1303-5.
AB: Reducing the number of accidents that are caused by drowsiness or fatigue could be achieved by applying different strategies. This paper focuses on the on-line, real-time detection of deteriorating driver state and driving behaviour, and on the question what should be done after this has been detected. It reports three studies performed in the TNO driving simulator. The first one leads to the conclusion that an in-vehicle monitoring device is best based on measures of steering activity, to which the registration of not keeping to one’s lane boundary could be added. The second study points

to the importance of certain personality attributes that determine who is a drowsiness-prone driver. The third study demonstrates that an alertness maintenance device (gamebox) can have positive effects on the onset of drowsiness and on the occurrence of critical events that it may cause. Altogether the results lead to a positive conclusion with respect to the possibility of implementing a strategy that focuses on the on-line detection of drowsiness and its consequences. Behavioural adaptation from the side of the relevant drivers to this strategy, however, is an issue of concern that needs further investigation. For the covering abstract, see ITRD E118917.
AN: E118933

Johnson, K.
SB: TRB-TRIS.
TI: How Many Hours Should a Trucker Drive?
SO: Traffic Safety. 2000/03. 00(2) pp. 14–16 (3 Phot.)
AB: The National Transportation Safety Board estimates that fatigue is a factor in half of all trucking-related crash fatalities annually. The government already has HOS regulations for truckers. The problem is that the rules were put in place in 1939. The Federal Highway Administration is set to release proposed changes to the regulations in spring 2000, with the final version of the new rules released in late 2000 or early 2001. Safety groups and government bodies say changes in HOS should be considered in the context of other relevant factors, including the body's "internal clock," payment methods for truck drivers, and driving time records. Current regulations say that for every 8 hr a trucker is off-duty, he can drive for 10 hr and work (loading and unloading) for as long as 5 more. A trucking industry newspaper reported that the new regulations would mandate a "14/10" schedule: 14 hr driving, 10 hr off. However, safety groups say that arrangement does not give drivers enough time to get home and actually sleep. They favor 12- to 14-hr rest periods with 10- to 12-hr driving limits.
AN: 00790606

Khardi, S.
SB: IRRD-OECD.
TI: Drowsiness of the Driver: EEG (Electroencephalogram) and Vehicle Parameters Interaction.
SO: Proceedings of the Fourteenth International Technical Conference on Enhanced Safety of Vehicles, May 23–26, 1994, Munich, Germany. Volume 1. 1995. (94-S3-O-06) pp. 443–61 (75 Refs.)
PY: 1995.
AB: Three factors are involved in car accidents: the road, the vehicle, and the driver. Of these, the first two have recently received considerable attention; the third factor, the driver behind the wheel, is probably the most important. Attention is paid to the last two factors. The present study characterizes low vigilance periods relative to driver's drowsiness by simultaneous analysis of the recorded electroencephalogram (EEG), steering wheel movements, and vehicle speed signals during a 6-hr driving period. The mechanical parameter thresholds of the vehicle are discussed. (a) For the covering abstract of the conference, see IRRD 894848.
AN: 894888

King, D.J., Mumford, D.K., and Siegmund, G.P.S.B.
IRRD-OECD.
TI: An algorithm for detecting heavy-truck driver fatigue from steering wheel motion.
SO: Proceedings of 16th International Technical Conference on the Enhanced Safety of Vehicles, Held Windsor, Ontario, Canada, 31 May–4 June 1998. Vol. 2. 1998/10. (DOT HS 808 759) pp. 873–82 (7 Refs.)
PY: 1998.
AB: This paper is the culmination of previous work to determine if steering behavior could be used to unobtrusively detect driver fatigue. The driving performance of 17 sleep-deprived heavy-truck drivers was monitored on a closed track. Functions in the time, frequency, and phase domains were developed to quantify changes in steering wheel input. The steering-based weighting functions which correlated most strongly with independent measures of driver fatigue and drowsiness were used to develop a simple algorithm. The algorithm predicted fatigue for all 17 volunteer drivers before the end of their test. The algorithm identified 12 drivers before a lane breach occurred, and only two drivers were not captured until a lane breach greater than 15-cm occurred. These data and the algorithm demonstrate the potential for a steering-based fatigue detection algorithm. (a) For the covering abstract, see IRRD E102514.
AN: E103116

Mabbott, N., Newman, S., and Moore, B.
SB: IRRD-OECD.
TI: Safety and productivity through flexibility: driving hours review.
SO: ARRB Transport Research Ltd. Conference, 20th, 2001, Melbourne, Victoria, Australia. 2001. 19 p.
PY: 2001.
RN: 0-86910-799-2.
AB: A review of the regulatory approach to heavy-vehicle driver fatigue in Australia has now commenced. The review will be led by the NRTC with participation from road authorities, the road transport industry, and others. The objective of the policy review is improvements in road safety and transport productivity through the development and implementation of policies and practices to assist in the management of fatigue in drivers of heavy vehicles. Issues to be considered in future policy development include the extent of the problem, results of recent research on circadian rhythms (time-of-day effects) and sleep/rest needs, the desirability of greater operator flexibility within safety constraints, the WA approach of a Code of Practice applied under OH&S legislation, and consistency between transport and OH&S requirements. It is likely that proposals for evaluation will involve a flexible range of

options from basic prescription to full fatigue management, all options consistent with the "duty of care" requirements of occupational health and safety legislation, and more widespread use of electronic record keeping, possibly as a prerequisite for increased flexibility. The latter part of this paper presents a summary of a project concerning flexibility options for regulated HOS. (a) For the covering entry of this conference, see ITRD E204173.
AN: E204227

Macchi, M.M., Boulos, Z., Ranney, T., Simmons, L., and Campbell, S.S.
"Effects of an afternoon nap on nighttime alertness and performance in long-haul drivers." Accident Analysis & Prevention. 2002/11. 34(6) 825–834.

Mahon, G.L.
SB: TRB-TRIS.
TI: New Approaches to Fatigue Management: A Regulator's Perspective.
CA: American Trucking Associations, Inc., Alexandria, VA, USA.
SO: Conference Title: Managing Fatigue in Transportation. Location: Tampa, Florida. Sponsored by: American Trucking Associations, Association of American Railroads, Federal Highway Administration, Federal Railroad Administration, National Highway Traffic Safety Administration, and National Transportation Safety Board. Held: 19970429–19970430. 1998. pp. 145–153 (Refs.)
PY: 1998.
RN: 0865875162.
AB: The Fatigue Management Program is an initiative by the Queensland Department of Transport to move toward performance-based legislation to manage a major occupational hazard—fatigue—in the road transport industry. The program targets the development and implementation of management training, schedules, and education programs that focus on fatigue and outlines the need for drivers to acquire amounts of quality sleep, develop strategies for avoiding sleep loss, and consider the behavioral and physiological consequences of tiredness. This will enhance awareness that sleep can occur suddenly and without warning to all drivers regardless of their age or experience and that fatigue has a serious effect on a driver's work performance and safety. Successful management of driver fatigue involves a cooperative approach between management and their drivers. It is about balancing the fatigue levels of each driver and providing the appropriate countermeasures to alleviate the impact or onset of fatigue.
AN: 00789176

Mercier-Buyon, C. (Ed.), Vallet, M., and Khardi, S.
SB: IRRD-OECD.
TI: Working Conditions and Fatigue Among Lorry Drivers: Alcohol, Drugs and Driving Safety: A Literature Study.
SO: Proceedings of the 14th International Conference of Alcohol, Drugs and Traffic—T'97, Held Annecy, France, 21–26 September 1997, Vol. 2. 1997. pp. 587–95 (33 Ref.)
PY: 1997.
RN: 2-9511746-0-8.
AB: Earlier work on the involvement of truck drivers in accidents is outlined. The author then examines in more detail evidence of the use of alcohol, medication, and narcotics. It is suggested that these factors may be linked to the working conditions experienced by truck drivers, in particular work duration, sleep deprivation, and fatigue. Attention is drawn to the occurrence of pathological sleeping disorders among professional drivers. For the covering abstract, see IRRD 893732.
AN: 894677

Moore-Ede, M., Heitmann, A., Guttkuhn, R., Trutschel, U., Aguirre, A., and Croke, D.
SB: TRB-TRIS.
TI: Circadian Alertness Simulator for Fatigue Risk Assessment in Transportation: Application to Reduce Frequency and Severity of Truck Accidents.
SO: Aviation, Space and Environmental Medicine. 2004/03. 75(3) pp.107–118 (7 Fig., 15 Ref.)
PY: 2004.
AB: The Circadian Alertness Simulator (CAS) was developed for assessing the risk of diminished alertness at work. The assessment of operational fatigue risk, work schedule optimization, and fatigue-related accident investigation are some of the applications of CAS. Sleep and alertness patterns are estimated based on the documented work schedules and the cumulative fatigue score is calculated. The free parameters of the algorithms were optimized using more than 10,000 sleep and alertness datasets collected from transportation workers performing their regular jobs. Heavy truck drivers involved in DOT-recordable or high-cost accidents were found to have significantly higher CAS fatigue risk scores than accident free drivers. Further examination of CAS risk assessment validity using scenarios provided in a fatigue modeling workshop indicated that the CAS model performed well in estimating alertness with a real-world transportation scenario of railroad locomotive engineer work-rest patterns.
AN: 00972989

Parrott, S.
SB: IRRD-OECD.
TI: Dead tired.
SO: Commercial Motor. 2000/02/03/09. 191(4860) pp. 44–5.
AB: According to recent researches, driver fatigue is blamed for 10% of all road accidents and up to 20% of motorway accidents in the United Kingdom; 25% of lorry drivers suffer from dangerous levels of fatigue on the road because they are too busy to take a break. This article discusses whether and to what extent their employers are to blame. Anyone in charge of a vehicle weighing at least 3.5 tons is liable to the EU drivers' hours laws, which limit driving time to 10 hr per day for

2 days per week and 9 hr per day for other days, and specify required rest periods. Unfortunately, there are several ways of distorting driving records made by tachographs, and law enforcement has at least one loophole. At present, transport is not yet covered by the EU Working Time Directive, which became law in the United Kingdom 1 October 1998 and limits the average working week to 48 hr, although the Transport & General Workers Union is urging an extension of this law. A questionnaire was sent to 220 drivers and 420 managers of lorries, asking them about their driving hours and breaks in relation to tiredness; the 720 replies showed quite high rates of bad practices. In January 2000, the road safety campaign group Brake held a conference for transport professionals concerned about fatigue, which produced useful advice for employers.
AN: E104633

Peters, R. D. Effects of partial and total sleep deprivation on driving performance. *Proceedings from Human Factors and Ergonomics Society*, Santa Monica, CA. Human Factors and Ergonomics Society Inc., 1995. Vol. 2, 935.
AB: The National Highway Traffic Safety Administration estimates that from 1989 through 1993, driver drowsiness/fatigue was a contributing factor in 100,000 crashes annually on U.S. highways. A recent study examined the effects of progressive sleep deprivation on driving performance to assess the rate of crashes and the changes in driving performance resulting from sleepiness. Because it would be unsafe to study this under real driving conditions, the high-fidelity highway driving simulator was used. A variety of measures, including continuous EEG monitoring, videotaping, and analyses of driving performance data and questionnaire data were used to determine the effects of sleep deprivation on the driving performance of six men and six women aged 26 to 35. Highway safety variables, including number of crashes and number of lane excursions, were unacceptably high on day 3 after 36 hr of no sleep and on day 4 after 60 hr without sleep. More subtle measures of highway safety such as speed and lateral placement variance were also linked to sleep deprivation. Although some trends appeared, none of the variables were significantly affected by partial sleep deprivation, perhaps because participants were young, very healthy, non-medicated and because they had no sleep debt at the start of the study. A preliminary neural net analysis using the data collected is underway. If patterns of driving performance can be identified, it will lend strong support for the development of a neural net in-vehicle-based system for detecting and warning drowsy drivers of potential danger.

Peters, R., Thomas, M., Welsh, A., Alicandri, E., Thorne, D., Sing, H., Wagner, E., and Belenki, G.
SB: TRB-TRIS.
TI: Fatigue-Related Accidents: What Really Happens Prior to a Crash?
CA: Human Factors and Ergonomics Society, Inc., Santa Monica, CA, USA.
SO: Conference Title: Human Factors and Ergonomics Society 42nd Annual Meeting, Proceedings. Location: Chicago, IL. Sponsored by: Human Factors and Ergonomics Society. Held: 19981005–19981009. 1998. 2 pp.
PY: 1998.
RN: 0945289111.
AB: Official statistics indicate a trend toward an increase in fatigue-related accidents over the past 5 years. It is widely believed that these official statistics grossly underestimate the role of fatigue in accidents. This collaborative study defined performance decrements that drivers experience under varying levels of partial and total sleep deprivation. A 4 (rested, partial, 36-hr, and 60-hr sleep deprivation) by 8 (type of roadway) by 2 (gender) mixed factorial design with repeated measures of driving performance in a high fidelity driving simulator was used to define these performance decrements. Analyses revealed several driving performance measures were significantly affected by sleep deprivation including number of crashes, lateral placement variance, speed, and lane excursions. Regression analyses showed that lateral placement variance was the best predictor of crashes. The most surprising finding was that most crashes were not directly preceded by microsleep events (defined here as 1 to 15 seconds of stage 1 sleep). It has long been assumed that in most circumstances, drowsy drivers have gotten into accidents by falling asleep, but this finding refutes that belief. Drowsy driver crashes may, in fact, be more directly related to the inattention and distractibility that accompany sleep deprivation than to falling asleep at the wheel.
AN: 00767979

Peters, R.D., Wagner, E.K., Alicandri, E., Fox, J.E., Thomas, M.L., Thorne, D.R., Sing, H.C., and Balwinski, S.M. "Effects of partial and total sleep deprivation on driving performance." (1999). Public Roads. 62(4) 2–6.

Ranney, T.A., Simmons, L.A., Boulos, Z. and Macchi, M.M.
SB: TRB-TRIS.
TI: Effect of an Afternoon Nap on Nighttime Performance in a Driving Simulator.
SO: Transportation Research Record. 1999. (1686) pp. 49–56 (4 Fig., 2 Tab., 32 Ref.)
PY: 1999.
RN: 0309071135.

Riley, M.W., Stentz, T.L. and Tarawneh, I.
SB: TRB-TRIS.
TI: Safety Impact Issues of Job-Associated Sleep.
CA: University of Nebraska, Lincoln, USA; Somnos Laboratories, Lincoln, NE, USA.
SO: 1997/09. pp. 127 (Tabs., Apps.)
PY: 1997.
RN: Report Number: MATC UNL96-2; Contract/Grant Number: DTRS95-G-0007.
AB: This research investigated the safety impact issues of job-associated sleep in truck drivers. The research focused on

the anonymous survey of professional truck drivers. Information was gathered regarding perception of driving performance and its relationship to sleep on the road. In addition to the survey, detailed information was gathered on a typical sleeper berth used by 65% of the respondents. All recommendations address issues that were identified by less than 85% of the respondents in the questionnaire. Thus, the potential impact of these recommendations can be low due to the small response sample of professional drivers. First, drivers should be medically screened and treated if necessary for sleep disorders. Second, special training and education is needed to help drivers improve their strategies to overcome fatigue and obtain more and better quantity sleep. Third, the presence of sleep deprivation in drivers, as a result of many contributing factors, indicates a need for a comprehensive design model for work-rest cycle planning. Fourth, the physical discomforts reported by drivers need additional investigation to determine the sources of exposure in order to facilitate exposure elimination or reduction.
AN: 00789661

Rothengatter, T. (Ed.), Carbonell-Vaya, E. (Ed.), Desmond, P.A., and Matthews, G.
SB: IRRD-OECD.
TI: The Role of Motivation in Fatigue-Related Decrements in Simulated Driving Performance.
SO: Traffic and Transport psychology. Theory and Application. 1997. pp. 325–34.
PY: 1997.
RN: 0-08-042786-3.
AB: The role of the driver's motivational state in eliciting fatigue-related decrements in driving performance has been largely neglected by researchers. However, its importance has been highlighted by McDonald (1984), who argues for motivational explanations for impairments in decisionmaking, judgment of risk and attention when driving is prolonged. Studies of fatigue in contexts other than driving also indicate that de-motivation and apathy are primary symptoms of fatigue, which are expressed in reduced effort on the task at hand (Craig and Cooper 1992). Hence the aim of the present study was to examine the effect of a motivational manipulation in reversing or reducing fatigue-related decrements in simulated driving performance. The authors also aimed to examine implications of motivational change for the design and use of in-vehicle countermeasures to driver fatigue. As in the Desmond and Matthews (1996) study, drivers performed both a fatiguing drive, in the first part of which a fatigue induction procedure was added to the primary task of driving, and a control drive without fatigue induction. The effects of the fatigue manipulation on drivers' subjective states were assessed by the selection of subjective measures used in the previous study. The motivational manipulation, an instruction that driving skill was under assessment, appeared in early and late stages of control and fatigue drives. Control of the lateral position of the vehicle was assessed before, during, and after the instruction. For the covering abstract, see IRRD 896859.
AN: 899040

Status Report. 2004/08/01. 39(7) pp. 2–3 (1 Phot.)
SB: TRB-TRIS.
TI: Try Again on Rules Governing Truck Driving Hours, Court of Appeals Tells FMCSA.
PY: 2004.
AB: The U.S. Court of Appeals has decided that rules issued by the Federal Motor Carrier Safety Administration (FMCSA) fail to take into consideration the safety and health of truck drivers. While FMCSAs proposed rules would have required a longer rest period between stretches of driving, they would also have extended the maximum allowable driving time and would not have required onboard recorders to monitor truckers hours of driving. The Court questioned the rationality of the FMCSA and specified that the agency focus on the safety of truck drivers rather than on promoting the economic well-being of the motor carrier industry.
AN: 00978338

Steinberg, C.
SB: TRB-TRIS To Health Group.
TI: A Study of Prevalence of Sleep Apnea among Commercial Truck Drivers.
SO: Tech Brief. 2002/07. pp. 4 (1 Ref.)
PY: 2002.
RN: Report Number: FMCSA-RT-02-080.
AB: Staying awake means staying alive. This is a slogan used to describe a research study on sleep apnea sponsored by the FMCSA and the American Transportation Research Institute of the American Trucking Associations. The research project addressed the prevalence of sleep apnea among CMV drivers, potential risk factors, and its impact on driving performance. This tech brief summarizes the project's final report, "A Study of Prevalence of Sleep Apnea Among Commercial Truck Drivers."
AN: 00932082

Stutts, J.C., Wilkins, J.W., and Vaughn, B.V.
SB: TRB-TRIS.
TI: Causes of Sleepiness in Drivers Who Crash.
CA: Association for the Advancement of Automotive Medicine, Barrington, IL, USA.
SO: Conference Title: Association for the Advancement of Automotive Medicine 45th Annual Proceedings. Location: San Antonio, Texas. Sponsored by: Association for the Advancement of Automotive Medicine. Held: 20010924–20010926. 2001. pp. 416–419 (3 Fig.)
PY: 2001.
RN: Report Number: Scientific poster.
AB: For the large majority of the driving public, sleepiness is likely due to one of three causes: not getting enough sleep on a routine basis; getting much less sleep than needed on a

short-term or single night basis; or not sleeping when one's biological clock is programmed to sleep. These three causes are the focus of the current study. Population-based samples of drivers in recent crashes were identified from North Carolina crash report forms as they were received at the Division of Motor Vehicles office in Raleigh, North Carolina. All cases in which the driver of a vehicle was coded as either "asleep" or "fatigued" by the investigating officer were identified, along with a random sample of control crash drivers. The identified drivers were then contacted for telephone interviews to obtain information on their work/sleep schedules and circumstances surrounding their crashes. Chronic sleep loss, acute sleep loss, and nighttime sleep disruption were all found to be important contributors to sleep-related motor vehicle crashes. Although certain segments of the population, including shift workers and persons with undiagnosed sleep disorders, are known to be at high risk for involvement in sleep-related motor vehicle crashes, the vast majority of such crashes involve individuals who either do not get enough sleep on a regular basis, got far too little sleep the night before their crash, and/or were trying to drive when their biological clocks were programmed for sleep.
AN: 00923459

Tech Brief. 1998/10. pp. 4 (1 Fig., 1 Tab., 1 Ref.)
SB: TRB-TRIS.
TI: PERCLOS: A Valid Psychophysiological Measure of Alertness as Assessed by Psychomotor Vigilance.
PY: 1998.
RN: Report Number: FHWA-MCRT-98-006.
AB: This tech brief summarizes an Intelligent Transportation System (ITS) study titled "Evaluation of Techniques for Ocular Measurement as an Index of Fatigue and as the Basis for Alertness Management." The study was funded in part by the FHWA's Office of Motor Carriers and managed by the National Highway Traffic Safety Administration (NHTSA). The project's goal was to evaluate the validity and reliability of several drowsiness-detection measures and technologies in a controlled laboratory setting and to analyze the effects of alerting stimuli on drivers' alertness levels. Of the drowsiness-detection measures and technologies evaluated in this study, the measure referred to as "PERCLOS" was found to be the most reliable and valid determination of a driver's alertness level. PERCLOS is the percentage of eyelid closure over the pupil over time and reflects slow eyelid closures ("droops") rather than blinks. A PERCLOS drowsiness metric was established in a 1994 driving simulator study as the proportion of time in 1 min that the eyes are at least 80% closed. FHWA and NHTSA consider PERCLOS to be among the most promising known real-time measures of alertness for in-vehicle drowsiness-detection systems. The results of this research support the development of a "first-ever" real-time drowsiness detection sensor that would measure the percentage of eyelid closure over the pupil, over time (i.e., PERCLOS).
AN: 00760599

Tech Brief, 1999/04.
Eye-activity measures of fatigue and napping as a fatigue countermeasure.
FHWA-MCRT-99-010.

Tech Brief. 1999/08. pp. 4 (3 Fig.)
SB: TRB-TRIS.
TI: Eye-Activity Measures of Fatigue and Napping as a Fatigue Countermeasure.
PY: 1999.
RN: Report Number: FHWA-MCRT-99-010.
AB: CMV driver inattention, particularly that due to fatigue, is widely recognized as an important safety issue in the transportation industry. This tech brief summarizes an Office of Motor Carrier and Highway Safety study to investigate the potential of an eye tracking system for detecting reduced driver alertness and to determine the impact of preventative napping on driver alertness and performance. The complete final report will be available from the National Technical Information Service.
AN: 00789191

Tech Brief. 2000/01. pp. 4 (1 Phot.)
SB: TRB-TRIS.
TI: Driver Alertness and Fatigue: Summary of Completed Research Projects, 1995–98.
RN: Report Number: FMCSA-MCRT-00-006.
AB: This document describes projects in the FMCSA's Driver Alertness and Fatigue Research and Technology (R&T) focus area that were completed during the years 1995 to 1998 under the former Office of Motor Carriers in the FHWA. The projects covered in this tech brief include Driver Fatigue and Alertness Study, Fitness-for-Duty Testing, CMV Rest Areas—Making Space for Safety, Multi-Trailer Combination Vehicle Stress and Fatigue, Validation of Eye and Other Psychophysiological Monitors, Local/Short Haul Driver Fatigue Crash Data Analysis, Shipper Involvement in HOS Violations, and Assessment of Electronic On-Board Recorders for HOS Compliance. In addition, 3 conferences dealing with driver fatigue are described.
AN: 00789182

Van Schagen, I.
SB: IRRD-OECD.
TI: Fatigue while driving: inventory of causes, effects, and measures. (Vermoeidheid achter het stuur: een inventarisatie van oorzaken, gevolgen en maatregelen.)
SO: 2003. (R-2003-16) 45 p. (67 Refs.)
PY: 2003.
AB: Also in the Netherlands there is an increasing awareness that driving while tired is an important factor in the occurrence of road accidents. This literature study aims at providing an overview of the knowledge and insights about the relationship between fatigue and road safety. The study shows that fatigue has many more causes than the time somebody

has been driving. Too little sleep or a poor quality sleep, the time of day, and stress situations all contribute to the occurrence of fatigue. Determining the extent to which fatigue plays a part in accidents occurring is extremely awkward. It is almost impossible to objectively diagnose fatigue. When the various foreign data sources are combined, it must be concluded that fatigue is a (partial) cause in 10 to 15% of all severe accidents. There is no reason to suppose that in the Netherlands this percentage is substantially different. The short-term possibilities of taking measures to reduce the number of fatigue-related accidents are limited, especially for the "normal" car driver. The only thing that can be done at the moment is in the sphere of information. In addition, for professional drivers, there are legal possibilities concerning driving hours, duration, and rest periods and their enforcement, but there is also the possibility of starting so-called fatigue management programs and propagating a safety culture within haulage companies. In the more distant future, there are possibilities in the sphere of intelligent systems that automatically detect and, if necessary, intervene. There are various promising developments, but their large-scale application will take some time. This report may be accessed by Internet users at: http://www.swov.nl/rapport/ R-2003-16.pdf.
AN: E206767

Van Winsum, W.
SB: IRRD-OECD.
TI: Age-related differences in effects of drowsiness on measures of driver behaviour and performance.
SO: 1999/01/05. (TM-99-C001) 23p (18 Refs.)
PY: 1999.
AB: In a driving simulator, the effects of time on task were measured on variables that measure drowsiness, driving performance, and steering behavior for groups of younger and older drivers. It was found that the fraction of time during which the eyes were closed is a good measure of drowsiness that is sensitive to the effects of time on task. Of all single variables that measure driver performance and impairment, the percentage of time during which any part of the vehicle exceeded one of the lane boundaries was the most strongly affected by time on task. Also, with progressing drowsiness, the amplitude of steering corrections increased toward larger values. This was caused both by larger error corrections in response to larger errors and by an increase in coarseness of the steering response. Large steering corrections proved to be the single best indicator of progressing impairment by drowsiness and fatigue. Older drivers performed poorer on lateral control of the vehicle compared with younger drivers. Also, driving performance of older drivers deteriorated more with time on task compared with younger drivers. However, there were no differences between younger and older drivers in the reliability and validity of the different measures for drowsiness, steering behavior, or driving performance.

Watson, G.S., Weiler, J.M., Woodworth, G.G., Qidwai, J.C., and Quinn, S.A.
SB: IRRD-OECD.
TI: An analysis of driving performance measures used to assess the effects of medications on drowsiness, sedation, and driving impairment.
SO: Proceedings of the First International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design, Held Aspen, Colorado, August 14–17, 2001. pp. 252.
PY: 2001.
AB: The objective of this paper was to discuss driving scenarios and associated driving performance measures on their ability to demonstrate drowsiness, sedation, and driving impairment. The basis of this paper was a study that utilized a randomized, double-blind, double-dummy, four-treatment, four-period crossover trial in the Iowa Driving Simulator (IDS). Participants were 40 licensed drivers with seasonal allergic rhinitis who were 25 to 44 years of age. Treatments were Fexofenadine, diphenhydramine, alcohol, or placebo, given at weekly intervals before participants drove for 1 hr in the IDS. Measures examined included coherence, amplitude, phase angle, RMS error, following distance and behavior, lane keeping, response to unexpected vehicle intrusion, and drowsiness. Study results show that sedating antihistamines impair driving performance as seriously as alcohol. Statistically significant but small correlations were found between subjective drowsiness and minimum following distance, steering instability, and left-lane excursions but no correlation was greater than 0.21. Drowsiness was a weak predictor of driving impairment. This paper discusses these and other findings with an emphasis on the adequacy of driving scenarios and the sensitivity of driving performance measures analyzed. For the covering abstract, see ITRD E113119.
AN: E113161

Williamson, A., Feyer, A.M., Friswell, R., and Finlay-Brown, S.
SB: IRRD-OECD.
TI: Development of measures of fatigue: using an alcohol comparison to validate the effects of fatigue on performance.
SO: Report. 2000/07. (CR 189) 72 p.
PY: 2000.
RN: 0-642-25579-2.
AB: This study was the first of a series looking at the development of model work-rest schedules that have demonstrated effectiveness in managing driver fatigue. The aim was to develop a range of performance tests with demonstrated sensitivity for fatigue and for which the fatigue effects could be interpreted on the basis of a community-accepted standard for safety. Performance effects were studied in the same subjects over a period of 28 hr of sleep deprivation and following measured doses of alcohol up to approximately 0.1% BAC. Subjects were 39 employees from the transport industry

and the army. After 17 to 19 hr without sleep, corresponding to approximately 10:30 p.m. and just after midnight, performance on some tests was equivalent or worse than that at 0.05% BAC. Response speeds were up to 50% slower for some tests and accuracy measures were significantly poorer at this level of alcohol. After longer periods without sleep, performance reached levels equivalent to the maximum alcohol dose given to subjects (0.1% BAC). The results also demonstrated that not all types of performance tests were affected by sleep deprivation. Also, differences between the performance of drivers and controls suggested that drivers took a more conservative approach to performance. This study demonstrated which of a set of performance tests can be used in evaluations of fatigue and fatigue countermeasures. The findings also reinforce evidence that the fatigue of sleep deprivation is important and likely to compromise speed and accuracy needed for safety on the road and in other industrial settings.
AN: E204278

Williamson, A.M., Feyer, A.M., Mattick, R.P., Friswell, R., and Finlay-Brown, S.
SB: IRRD-OECD.
TI: Developing measures of fatigue using an alcohol comparison to validate the effects of fatigue on performance.
SO: Accident Analysis & Prevention. 2001/05. 33(3) pp. 313–26 (40 Refs.)
PY: 2001.
AB: The effects of 28 hr of sleep deprivation were compared with varying doses of alcohol up to 0.1% BAC in the same subjects. The study was conducted in the laboratory. Twenty long-haul truck drivers and 19 people not employed as professional drivers acted as subjects. Tests were selected that were likely to be affected by fatigue, including simple reaction time, unstable tracking, dual task, Mackworth clock vigilance test, symbol digit coding, visual search, sequential spatial memory, and logical reasoning. While performance effects were seen due to alcohol for all tests, sleep deprivation affected performance on most tests, but had no effect on performance on the visual search and logical reasoning tests. Some tests showed evidence of a circadian rhythm effect on performance, in particular, simple reaction time, dual task, Mackworth clock vigilance, and symbol digit coding, but only for response speed and not response accuracy. Drivers were slower but more accurate than controls on the symbol digit test, suggesting that they took a more conservative approach to performance of this test. This study demonstrated which tests are most sensitive to sleep deprivation and fatigue. The study therefore has established a set of tests that can be used in evaluations of fatigue and fatigue countermeasures.

Yarrow, R.
SB: IRRD-OECD.
TI: Wake up call.
SO: Auto Express. 2000/11/22. (629) pp. 35–6.
PY: 2000.
AB: The results are detailed of a trial carried out at the Sleep Research Centre, Loughborough University, into the effects of caffeine-packed soft drinks on sleepy drivers. According to the Department of Environment, Transport and Regions' statistics, 1 in 10 of all accidents on UK roads are caused by people falling asleep with 1 in 5 of accidents on motorways. The trial consisted of fifteen sleep-deprived drivers being tested in a car simulator. The results show the effects on driving performance of sleep-deprivation and how taking a high-energy soft drink can virtually overcome the effects of a lack of sleep for a limited time.
AN: E108633

APPENDIX A

PROJECT STATEMENT OF WORK

(I) Literature Review on Health- Related Issues Associated with Hours of Work

Literature review of the body of scientific research concerning HOS and CMV operator health. The purpose of the literature review is to provide information that clearly discusses in a scientific, experimental, and quantitative way the relationship between the hours a person works or the structure of the work schedule (on-duty/off-duty cycles, sleep time, etc.) and the impact on some medical conditions. The search should be limited to studies conducted in the United States, Canada, Australia, or European Union on CMV operators on interstate highways, transit systems, aviation, and maritime transportation. Studies that do not correspond to these specifications can be included in the review if the panel deems them important for understanding specific scientific developments. The results of the review shall be presented in language understandable to a non-subject matter expert.

Period to be covered: 1975 to present

Suggested topics to be covered

(1) CV Operator
(2) CV Operator Health Issues
(3) Age and gender
(4) Lifestyle (e.g., exercise, diet)
(5) Driving hours
(6) Duration of workweeks
(7) Length of sleep time and sleep deprivation
(8) Shift work
(9) Schedule regularity and irregularity
(10) Exposure to harmful/toxic substances
(11) Occupational health: cardiovascular (e.g., blood pressure), immune system, diabetes, gastrointestinal, musculoskeletal (e.g., lower back pain, sciatica), hearing and vision, mental health, sleep disorders, obesity, sleep apnea

Additional questions

(a) Is there any scientific literature that addresses specifically the relationship between number of driving hours above a certain threshold and operator's health issues?
(b) Is there any scientific literature addressing health concerns in the areas of musculoskeletal, vibration, noise, blood pressure, as manifested in the 11th hour of driving?
(c) Is there any scientific literature addressing gender-specific reaction to some conditions, such as environmental heat?

Suggested panel leader

Michael Belzer or Gerald Krueger

Suggested panel members

* Roger Rosa, PhD. (NIOSH): Shift work
* Ellison Wittels, MD: Cardiovascular:
* John Sheridan, PhD.: Diabetes (John leads FMCSA support services contractor team on the diabetes program)
* Melvyn Sterling, MD: Gastrointestinal, musculoskeletal, hearing
* Gerald Krueger, PhD., and James W. Curran, MD: Wellness
* Lee Husting or Stephanie Pratt (both of NIOSH): Occupational safety
* Peter Orris, MD and Toni Alterman (NIOSH): Occupational health
* Kenneth Wells, MD: Mental health
* David Dinges, PhD. (University of Pennsylvania): Sleep disorders

(II) Literature Review on Fatigue Issues Associated with Hours of Work

Literature review of the body of scientific research concerning HOS and CMV operator performance and fatigue health. The purpose of the literature review is to provide information that clearly discusses in a scientific, experimental, and quantitative way the relationship between the hours a person works or the structure of the work schedule (on-duty/off-duty cycles, time on task, sleep time, etc.) and the impact on driver fatigue and performance. The search should be limited to studies conducted in the United States, Canada, Australia, and European Union on CMV operators on interstate highways, transit systems, aviation, and maritime transportation. Studies that do not correspond to these specifications can be included in the review if the panel deems them important for understanding specific scientific developments. The results of the review shall be presented in language understandable to a non-subject matter expert.

Period to be covered: 1995 to present

Suggested topics to be covered

(1) CMV Operator
(2) CMV Operator Performance Issues
(3) Age and gender
(4) Lifestyle (e.g., exercise, diet)
(5) Driving hours
(6) Duration of work weeks
(7) Length of sleep time and sleep deprivation
(8) Shift work
(9) Time on task
(10) Schedule regularity and irregularity
(11) Exposure to harmful/toxic substances
(12) Sleep deprivation countermeasures, e.g., naps
(13) Hours-of-service regulations: general considerations, schedules, shift rotation, multi-day shifts, outcomes of pilot tests and waivers, operational and performance models
(14) Technological approaches to CMV driver alertness management

(15) Personal wellness
(16) Alertness
(17) Fatigue
(18) Distraction
(19) Reaction time

Additional questions

(a) Is there any scientific literature that addresses specifically the relationship between number of driving hours above a certain threshold and operator's fatigue?
(b) Is there any research that shows how fatigue builds or does not build under certain conditions or scenarios, e.g., 11/14 hr driving/working days, working more than 60 hr in 7 days?
(c) Is there any scientific literature that focuses on the impact on fatigue of splitting the sleep time into shorter periods?
(d) Are there documented differences in the quality of sleep between when the truck is parked vs. when the truck is in motion?
(e) Is there research on the definition of a cumulative fatigue factor and the factors that affect it??

Suggested panel leader

Alison Smiley, Transport Canada

Suggested panel members

* David Dinges, PhD. (University of Pennsylvania): Sleep disorders
* Roger Rosa, PhD. (NIOSH): Shift work
* Ellison Wittels, MD: Cardiovascular:
* Gerald Krueger, PhD., and James W. Curran, MD: Wellness
* Lee Husting or Stephanie Pratt (both of NIOSH): Occupational safety
* Peter Orris, MD and Toni Alterman (NIOSH): Occupational health
* Kenneth Wells, MD: Mental health
* Gregory Belenky, PhD.
* Tom Dingus, PhD. (VTTI)
* Merrill Mitler

Note: There are several experts on both panels because they represent suggestions coming from FMCSA. The panel leader will choose the actual panel members based on their knowledge and on the expert's availability. It is expected that there would be three people on each panel in addition to the panel leader.

Suggested process for each review

1. Preparation (Weeks 1 and 2)
    1.1. The panel leader meets with FMCSA to clarify the scope of the literature review
    1.2. Based on the suggestions received from FMCSA and his/her own knowledge, the Panel leader forms a panel of experts that will support the literature review
    1.3. The panel leaders develop an outline of the Literature Review Report
    1.4. The panel leader reports progress to FMCSA and gets consensus on the outline
2. Development of preliminary findings (Weeks 2 through 8)
    2.1. The panel leader, with the support of the experts of the panel, assembles a list of papers for the literature review
    2.2. The panel leader summarizes the most significant papers on the list and prepares an interim report with preliminary findings
    2.3. FMCSA reviews the interim report and provides feedback to the panel leader and to the panel of experts on the continuation of the effort
3. Development of the literature review report (Weeks 8 through 12)
    3.1. The panel leader develops, with the help of the panel members, the draft literature review according to the agreed outline
    3.2. The panel leader sends the draft to the panelists for comment and integration
    3.3. The panel leader updates the draft
    3.4. The panel leader presents the draft to FMCSA
    3.5. FMCSA reviews the draft and provides comments
4. Development of the final version of the literature review report (Weeks 12 through 14)
    4.1. The panel leader updates, with the help of the panel members, the draft literature review
    4.2. The panel leader briefs FMCSA on the findings and delivers the final version to FMCSA

Part II

Review of References Related to Public Comments

LITERATURE REVIEW ON HEALTH AND FATIGUE ISSUES ASSOCIATED WITH COMMERCIAL MOTOR VEHICLE DRIVER HOURS OF SERVICE

Part II: Review of References Related to Public Comments

SUMMARY

Since 1995, the U.S. Department of Transportation's Federal Motor Carrier Safety Administration (FMCSA) [formerly FHWA's Office of Motor Carriers] actively conducted a concentrated program of research, study, and industry outreach education on commercial driver alertness, fatigue, health and wellness. There was much open public discussion, deliberation, and negotiation over the public rulemaking process from 1996 to 2003. In May 2003, FMCSA issued new Hours of Service (HOS) rules for commercial truck drivers with a planned implementation date in January 2004. After substantial amounts of training and preparation by government and the trucking industry, those new HOS rules went into effect January 4, 2004.

The January 2004 revised HOS rules extended allowable driving time to 11 hours and reduced overall driver work hours to 14 before requiring a 10-hour break. The old HOS rules limited commercial truck driving to 10 hours and allowed drivers to work 15 hours before taking a mandatory 8-hour break.

Public Citizen challenged those HOS rules in a lawsuit, alleging that the new HOS did not properly account for commercial driver health concerns. Responding to that lawsuit, in July 2004, the U.S. Court of Appeals for the Washington District of Columbia Circuit ruled that DOT's FMCSA did not consider truck drivers' health in the revised HOS rules. FMCSA requested the federal court to stay its order and to keep the current, revised HOS rules in effect until FMCSA could present its case again or could prepare a new set of HOS rules.

As one part of its efforts to reply to the Court of Appeals ruling on HOS, the FMCSA requested independent technical assistance from a third-party research team to summarize the scientific and technical literature on commercial vehicle operator health, wellness, fatigue, and performance, as they might be related to the hours a person works or to the structure of the work schedule (e.g., on-duty/off-duty cycles, sleep time, etc.).

MaineWay Services was assigned the task of literature review by the Transportation Research Board (TRB). This synthesis was completed and submitted to TRB for review and publication.

OBJECTIVE OF SUPPLEMENTAL REVIEW

On January 24, 2005, FMCSA published in the Federal Register (70 FR 3339) a Notice of Proposed Rulemaking (NPRM) regarding HOS of commercial motor vehicle (CMV) drivers. In that NPRM, FMCSA announced its intention to review and reconsider the regulations on HOS of drivers published on April 28, 2003, and amended on September 30, 2003. In the docket to this January 24, 2005, NPRM, FMCSA refiled the same Regulatory Impact Analysis (RIA), or comprehensive analysis of economic benefits and costs of the proposed rule, as was filed in the docket for the April 2003 final rule.

Within the responses to this request for comments on this announcement were some 266 references to studies, articles, and literature relating to the health and fatigue effects of the HOS regulations. To assess the significance and relevance of these references, the MaineWay Services research team was asked to review the studies, articles, and literature and provide analyses of those references it deemed relevant to the health and fatigue effects of the existing regulations.

RESEARCH TEAM

The research team consisted of the following members:

Health Effects Panel

Peter Orris, MD, MPH

- Professor of Occupational and Environmental Health Sciences, University of Illinois School of Public Health, Cook County Hospital
- Director of Occupational Health Services Institute, Great Lakes Center for Occupational and Environmental Safety and Health, University of Illinois
- Chief of Service, Occupational and Environmental Medicine, University of Illinois at Chicago Hospital and Medical Center
- President, Medical Staff, Cook County Hospital
- Secretary/Treasurer, Journal of Public Health Policy
- Member of Medical Advisory Committee of International Brotherhood of Teamsters
- Author of multiple publications relating to public health topics and reviewer and participant in editorial boards of a range of professional journals related to public health topics

Susan Buchanan, MD, MPH

- Interim Program Director, Occupational Medicine Residency, UIC College of Medicine
- Author, several publications relating to Occupational Health
- Reviewer, *American Journal of Industrial Medicine,* 2004

Health Effects Panel Members

- **Leslie Stayner, PhD.**
  - Professor and Director, Epidemiology and Biostatistics, University of Illinois, Chicago School of Public Health
  - Served as Chief of Risk Evaluation branch, National Institute for Occupational Safety and Health, Education and Information Division, and in several other career positions relating to risk evaluation
  - Contributing Editor to *Journal of Industrial Medicine,* and involved in a wide range of professional activities relating to industrial health
- **Eric Garshick, MD, MOH**
  - Assistant Professor of Medicine, VA Boston Healthcare System, Channing Laboratory, Brigham and Women's Hospital, Harvard Medical School
  - Served as Advisor, World Health Organization; International Program on Chemical Safety, Environmental Health Criteria for Diesel Fuel and Exhaust Emissions, Geneva Switzerland
  - Served as Consultant, U.S. EPA Science Advisory Board, Clean Air Scientific Advisory Committee Diesel Emissions Health Document
- **William Marras, PhD.**
  - Co-Director, Institute of Ergonomics, Ohio State University
  - Professor, Department of Physical Medicine, Biomedical Engineering Center, Ohio State University
  - Associate Editor, *Human Factors*
- **Natalie Hartenbaum, MD, MPH**
  - President and Chief Medical Officer of OccuMedix, Inc.
  - Adjunct Assistant Professor of Emergency Medicine/Occupational Medicine at the University of Pennsylvania
  - Editor-in-Chief of *CDME (Commercial Driver Medical Examiner) Review*

Fatigue Effects Panel

Alison Smiley, PhD.

- President of Human Factors North, Inc., a Toronto-based human factors and engineering consulting company; and a Canadian Certified Professional Ergonomist (CCPE)
- 30 years experience in measurement of human performance, and human factors consulting, specializing in driver behavior, transportation safety, and shift work
- Senior specialist in assessment of work-rest schedules, shift work, hours of work and worker rest for transportation industries (railways, coast guard and marine vessels, trucking, etc.) and for nuclear power plant and manufacturing operations
- Project manager for several Transport Canada projects involving literature review and development of experimental protocols related to fatigue and minimum recovery periods for CMV drivers
- Forensic consultant with expertise on car and truck driver fatigue and shift-scheduling issues
- Consultant to both Canadian and U.S. governing bodies on trucking industry hours of service regulations

Dianne Davis, M.Eng.

- Associate Consultant, Human Factors North, Inc.
- Over 10 years experience conducting human factors analyses in a variety of different domains such as the safety of driver examination tests, the study of fatigue and truck driving, way-finding, and the design of medical mobile devices and online shipping tools

ORGANIZATION AND PRESENTATION OF PART II: REVIEW OF REFERENCES RELATED TO PUBLIC COMMENTS

This supplemental references review is presented in two sections: Health Effects and Fatigue Effects.

The Health Effects section has the following subsections:

- Executive Summary
- Process and Methodology
- Review of References
- Reference Summaries

The Fatigue Effects section has the following subsections:

- Selection Criteria
- Executive Summary
- Reference Summaries

Note: The sections are presented in a format prescribed by the FMCSA HOS Regulatory Review Team subsequent to the publication of the initial statement of work.

HEALTH EFFECTS REFERENCES REVIEW

EXECUTIVE SUMMARY

The purpose of Part I of this synthesis was to provide information that clearly discussed in a scientific, experimental, qualitative, and quantitative way the relationship between the hours a person works, drives, and the structure of the work schedule (on-duty/off-duty cycles, time on task, especially time in continuous driving, sleep time, etc.) and the impact on the health of truck drivers. The issues of cardiovascular disease, cancer, musculoskeletal disorders, gastrointestinal disorders, reproductive health effects, and the effects of vibration and noise were reviewed in this part. Part II covers additional articles on lung cancer and the health effects of short sleep duration.

In Part II, the research team reviewed additional available information provided with respect to data relevant to driver health potentially associated with the 2003 HOS Regulations. FMCSA provided a list of 266 references included in comments on the proposed rules. After review of the titles or abstracts, 256 were judged to cover matters that were either previously reviewed in Part I or were outside the scope of Part II, which focused solely on health effects, and not on the fatigue effects discussed in a later section of this review. The research team focused on references which utilized a scientific approach in analyzing new data. Ten references were chosen and summarized based on the relevance of the article to the health effects of the changes in HOS for truck drivers. This review excluded articles that evaluated the health impact of shift work.

As stated in Part I, the literature indicates that lung cancer is likely caused by exposures to diesel exhaust and the longer that exposure lasts the more likely it is that a cancer will develop. Additional evidence for this association was found in the additional material reviewed yet tempered with respect to truck drivers with the understanding that substantial exposure misclassification may have occurred in job-derived exposure estimates.

An additional article (not included in Part I) on the relationship of whole body vibration (WBV) and self-reported low back pain again identified an association, although the association was weak.

Finally, an additional study (not included in Part I) suggested that, in contrast to prior results, short sleep duration, as low as 4.5 hours, may not affect mortality. Yet, the literature on sleep duration and health concludes that there is sufficient reason to be concerned about a possible link between long hours and physical health outcomes such as cardiovascular disease and diabetes. Several investigations of the acute biochemical effects of acute sleep restriction supported this concern due to the increase in risk factors for diabetes and obesity and an additional study noted that self-reported daily short sleep duration was associated with an increase in the rate of diabetes.

PROCESS AND METHODOLOGY

Literature Search Source and Terms

FMCSA provided a list of 266 references cited in public comments on the advanced NPRM.

Selection Criteria

The original list provided by the FMCSA contained 266 articles. Those not deemed appropriate by title (not relating to health effects) were eliminated, although the fatigue section of Part II includes those references relating to fatigue effects. The preliminary draft list then included 73 articles. Those not pertaining to health effects of truck driving or a related exposure, duration of work shift or duration of sleep were then removed from the list. Several citations taken from lay press websites and those already reviewed in Part I were also eliminated. Articles on shift work were likewise not included unless they specifically addressed short sleep duration.

The remaining ten references were summarized by a primary reviewer based on the validity of the methodology, the relevance of the studied population to truck driving, and the quality of the statistical analysis of health outcomes. These were abstracted and summarized in the format prescribed by FMCSA. The three end points covered by these new references were (1) lung cancer, (2) WBV, and (3) the health effects of short sleep duration.

REVIEW OF REFERENCES

The summaries are divided into the following subsections: lung cancer, WBV, and health effects of short sleep duration.

Lung Cancer

Three articles addressed the association of lung cancer and exposure to diesel exhaust. A case-control study using a survey of the general population in Sweden (Gustavsson et al. 2000) found a positive association as well as a dose-response relationship.

Two additional reports were reviewed that evaluated the strength of the methodologies of existing studies on the relationship of truck driving to lung cancer. An extensive feasibility study conducted by the Health Effects Institute Diesel Epidemiology Working Group (Garshick et al. 2002) demonstrates with its pilot data that long-haul drivers have a low exposure to diesel exhaust compared with dock workers and suggests that new diesel technology may be an explanation. They also note that estimating exposure based on job alone, as is done in many studies, may give highly misclassified exposure assignments. Similarly, in an analysis of the risk assessment data by the same panel (HEI 1999), recommendations were made regarding Quantitative Risk Assessment (QRA) based on the current studies available. The research team concluded that the railroad worker cohort study (Garshick 1988, a secondary reference in Part I) has limited utility for qualitative risk assessment, but that the Steenland article (1998) also reviewed for Part I is potentially useful based on a QRA approach.

The report, *Diesel and Health in America: the Lingering Threat*, from the Clean Air Task Force in February 2005 modeled the health effects of the current diesel fleet on the U.S. population as a whole (Schneider and Hill 2005). Despite the necessary assumptions inherent in this type of report, this study concludes that increasing the weekly working hours of drivers is likely to increase their risk of cancer with the understanding that new trucks, through changes in engine and cab design, will mitigate this affect due to reduction in exposure.

WBV Effects

In addition to the articles reviewed for Part I on the effects of WBV, one article reviewed for Part II (Palmer et al. 2003) showed a weak association between estimated vibration dose and low back pain. However, this was a survey of the general population and vibration dose was estimated from self report of vehicle use; both factors may explain the weaker association compared with previously reviewed studies of exposed workers.

Health Effects of Short Sleep Duration

A large study using data from 1.1 million questionnaires (Kripke et al.) investigated the mortality associated with short sleep duration and found that the best survival was experienced by those reporting a usual sleep duration of 7 hours. When controlled for co-variants, the mortality risk associated with short sleep all but disappeared, suggesting in contrast to prior studies that short sleep duration, as low as 4.5 hours, may not affect mortality.

A review of the literature on sleep duration and health (Alvarez 2004) concludes that the metabolic changes associated with short-term sleep deprivation may provide a potential mechanism for the effects of long-term sleep deprivation on health. An extensive review of the literature on long working hours by the United Kingdom Safety Laboratory (White 2003) only briefly includes the health effects of long hours. It concludes that there is sufficient reason to be concerned about a possible link between long hours and physical health outcomes such as cardiovascular disease and diabetes.

Three studies addressed the metabolic changes which may result from acute sleep restriction. A controlled study of sleep restriction in healthy volunteers (Spiegel 1999) showed carbohydrate intolerance, and cortisol and thyrotropin abnormalities similar to those seen in patients with type 2 diabetes and aging. On the other hand, a survey study of sleep duration with a sleep-lab component (Taheri 2004) did not find an association between sleep duration and insulin or glucose. However, two hormones which control appetite were both found to be abnormal in sleep-deprived participants.

Finally, large survey study of self-reported sleep duration and incidence of diabetes (Ayas et al. 2003), found a significantly elevated risk of diabetes in those sleeping ≤5 hours per night which disappeared when elevated Body Mass Index (BMI) (a known risk factor for diabetes) was not controlled for. As BMI or obesity may itself be associated with short sleep duration based on the studies of acute sleep deprivation, this may not be an appropriate control as the effect may be mediating rather than confounding.

REFERENCE SUMMARIES**

Reviewer: Susan Buchanan

Complete Title: The Impact of Daily Sleep Duration on Health: A Review of the Literature. Alvarez, G.G., Ayas, N.T. Prog Cardiovasc Nurs 2004;19(2): 56–59.

Abstract: A healthy amount of sleep is paramount to leading a healthy and productive lifestyle. Although chronic sleep loss is common in today's society, many people are unaware of the potential adverse health effects of habitual sleep restriction. Under strict experimental conditions, short-term restriction of sleep results in a variety of adverse physiologic effects, including hypertension, activation of the sympathetic nervous system, impairment of glucose control, and increased inflammation. A variety of epidemiologic studies have also suggested an association between self-reported sleep duration and long-term health. Individuals who report both an increased (>8 h/d) or reduced (<7 h/d) sleep duration are at modestly increased risk of all-cause mortality, cardiovascular disease, and developing symptomatic diabetes. Although the data are not definitive, these studies suggest that sleep should not be considered a luxury, but an important component of a healthful lifestyle.

Methodology: This was not a scientific study. It was a review article, but not a methodic literature review.

Scope of Work: To discuss the physiologic effects of short-term and long-term sleep restriction and examine the relationship between sleep restriction or sleep excess and a variety of health outcomes such as all-cause mortality, coronary heart disease (CHD), and diabetes.

Findings Directly Related to HOS (include page references):

Driver Health (General)

On short-term sleep restriction: mentions Spiegel's article (reviewed for Part II) showing impaired glucose tolerance and reduced leptin, etc., with acute sleep deprivation as well as another study by Meier-Ewert showing increased C-reactive protein with 4.2 hours of sleep per night.

"Although the magnitude of the physiologic changes found in these short-term studies was modest, they provide a potential mechanism whereby long-term sleep restriction may affect long-term health. However, the experiments described above predominantly studied young, healthy subjects and it is not known if similar changes would be found in older subjects." (There were no page numbers in e-file.)

On long-term sleep restriction: mentions the Nurses Health Study by Ayas showing a significantly increased risk of cardiovascular disease with ≤5 hours of sleep per night. Another article by Ayas using the same cohort (reviewed for Part II) which examined the risk of diabetes, was noted for its lack of significant association after adjusting for multiple co-variates. Also noted was the fact that these studies were done on women only so they should not apply to men. They were also criticized for using self-reports of sleep duration and for possible residual confounding.

Longer sleepers: several studies note increased mortality, not useful for our purposes.

Reviewer's Notes: This article is a review of the literature on health effects of sleep deprivation. It supports the findings of other studies reviewed for Part II, specifically the Spiegel and Ayas articles.

**Summaries are provided in the order submitted by the researchers.

Reviewer: Susan Buchanan

Complete Title: A Prospective Study of Self-Reported Sleep Duration and Incident Diabetes in Women. Najib T. Ayas, MD, David P. White, MD, Wael K. Al-Delaimy, MD, PhD., Joann E. Manson, MD, DRPH, Meir J. Stampfer, MD, DRPH, Frank E. Speizer, MD, Sanjay Patel, MD, Frank B. Hu, MD, PhD. *Diabetes Care* 26:380–384, 2003.

Abstract: Short-term sleep restriction results in impaired glucose tolerance. To test whether habitually short sleep duration increases the risk of developing diabetes, we studied a cohort of 70,026 women enrolled in the Nurses Health Study, without diabetes at baseline, and who responded to a question about daily sleep duration in 1986. Subjects were followed until 1996 for the diagnosis of diabetes (1,969 cases). Long and short sleep durations were associated with an increased risk of diabetes diagnosis. The relative risks (RRs) for short (slept <5 h per day) and long (slept >9 h per day) sleepers were 1.57 (95% CI 1.28–1.92) and 1.47 (1.19–1.80), respectively. After adjustment for BMI and a variety of confounders, the RR was not significantly increased for short sleepers (1.18 [0.96–1.44]) but remained modestly increased for long sleepers (1.29 [1.05–0.59]). We then performed a similar analysis using only symptomatic cases ($n = 1,187$). Adjusted RRs for symptomatic diabetes were modestly elevated in both short (1.34 [1.04–1.72]) and long (1.35 [1.04–1.75]) sleepers. Our data suggest that the association between a reduced self-reported sleep duration and diabetes diagnosis could be due to confounding by BMI or sleep restriction may mediate its effects on diabetes through weight gain. Sleep restriction may be an independent risk factor for developing symptomatic diabetes.

Methodology: The Nurses Health Study Cohort was used. In 1986, subjects were asked about total hours of sleep. Between 1986 and 1996, the incidence of diabetes was assessed with a supplementary questionnaire (to confirm the diagnosis). Relative risk for diabetes was calculated in the different categories of exposure (hours of sleep per night), adjusted for age. Multivariate analysis included age, smoking status, hypertension, alcohol consumption, physical activity, menopausal status, family history of diabetes, and hyperlipidemia. BMI was adjusted for in secondary analysis.

Scope of Work: To assess the relationship between self-reported sleep duration and the diagnosis of diabetes.

Sample Size: 70,026 nurses in the United States

Industry Sector: Nurses

Major Limitations: Old criterion for diabetes was used (FBS < 140). Current diagnostic criteria are stricter and would have resulted in more cases of diabetes, if used.

Findings Directly Related to HOS (include page references):

Driver Health (General)

Those who slept ≤5 or 6 hours per night showed significantly elevated relative risks (adjusted for age.) After adjusting for covariates, results remained significant but attenuated. After adjustment for BMI, the short sleepers were no longer at risk.

Reviewer's Notes: Results were modest and disappeared when adjusted for BMI, a known risk factor for diabetes. A modest study (due to the results, not the design).

Reviewer: Susan Buchanan

Complete Title: Quantitative Risk Assessment of Lung Cancer Risk from Diesel Exhaust Exposure in the U.S. Trucking Industry: A Feasibility Study. Garshick, E., Smith, T.J., Laden, F. Health Effects Institute Diesel Epidemiology Working Group 2002. pp. 115–149.

Abstract: The objectives of this study were to test the feasibility of identifying a population exposed to diesel exhaust in which small to moderate excesses in lung cancer could be estimated with reasonable precision and to develop a strategy to provide quantitative estimates of current and past exposures. We chose to assess the feasibility of designing an epidemiologic study based in the U.S. trucking industry. With cooperation of the Motor Freight Carriers Association (the trucking industry trade association) and the International Brotherhood of Teamsters (Teamsters Union), 4 large unionized national trucking companies agreed to participate in the feasibility study. We obtained samples of personnel, payroll, and truck inventory records and interviewed long-term employees, record managers, and senior management. The types of retirement records available from 2 large Teamsters union pension funds were determined. A pilot questionnaire was mailed to 526 employees at one terminal to obtain information on smoking behavior and job history. Short-term variations in exposure were assessed by measurement of air quality in truck cabs, loading docks, and yards in 2 large urban terminals and 4 small rural terminals. Measurements included elemental carbon (EC*) and organic carbon (OC) particles 2.5 µm or smaller in diameter, and respirable particulate clusters 2.5 µm or smaller in aerodynamic diameter (PM2.5). The OC collected in high-volume area samples was further analyzed to assess the extent to which particles collected in the loading dock area came from diesel vehicles. Past studies and outside exposure databases were reviewed.

Major determinants of exposure included an individual's job title, terminal size, and terminal location. A gradient of exposure was identified. Smoking behavior did not differ between long-haul drivers and other workers. In 1985, the number of male union workers at the 4 companies whose job history could be characterized was 55,750, and in 1999, it was 72,666. A retrospective cohort study of workers from the cooperating trucking companies and the Teamsters union alive in 1985 with mortality assessed through 2000 would have a greater than an 80% power to detect a relative risk of lung cancer of 1.25 to 1.29 attributable to diesel exposure. Thus, epidemiologic studies can be designed to study the occurrence of lung cancer and to estimate past exposures to diesel exhaust among employees of the trucking industry.

Methodology: The four largest unionized trucking companies in the U.S. were used to assess the quality of records of personnel, equipment, payroll, operations, and retirement in order to reconstruct job and exposure histories. Exposure was assessed at 2 large terminals in an urban area and at 4 small terminals in rural New England. Personnel database assessment included work history records and Teamsters Union employment records. Assessment of company data of truck fleets included inventory and maintenance records, vehicle purchasing, and retirement. Terminals were assessed for design, operations, and location (urban, rural).

Field tests, including both personal and fixed location sampling, were conducted to obtain some limited data on current exposures to diesel exhaust.

Scope of Work: To determine the feasibility of designing an epidemiologic study to assess lung cancer risk from long-term exposure to diesel exhaust for the purpose of hazard identification and risk assessment based on exposure estimates.

Sample Size: Thirty workers in the pilot exposure measurement part of the study. Four trucking companies with a total of 72,666 workers were included in the feasibility assessment. 526 employees participated in the pilot questionnaire part of the study.

Industry Sector: Trucking industry, both short and long haul

Major Limitations: This is a feasibility study only. The data collected were for use in estimating feasibility and not for investigating the association between exposure to diesel exhaust and lung cancer.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Long-haul drivers had the lowest and dock workers had the highest exposure levels to organic carbon, PM2.5 and elemental carbon (n = 30). However, when looking at correlation between the levels, "Assuming that EC represents diesel exposure in these settings, these results show that PM 2.5 would be a poor marker of diesel exposure and the OC would add little information (although the sampling numbers are small.)" (p. 131)

Regarding area samples: "These data show that even in rural locations the existence of diesel sources near the terminal can increase exposure levels." (p. 132)

Comparison to NIOSH Health Hazard Evaluation exposure data (Zaebst 1989): "Exposures of long haul drivers were much lower in our Atlanta data than in the Zaebst data, which may reflect the effect of new diesel technology." (p. 134)

Regarding estimation of previous exposures: "For this cohort, the results showed that job alone might give highly misclassified exposure assignments. This definition should be refined by including terminal characteristics and formulating job-terminal exposure categories for historical periods." (p. 138)

Power calculations were presented for 3 exposure scenarios and demonstrated the feasibility of detecting a significant trend across exposure groups with relative risks of 1.27–1.33 at 80% power.

Reviewer's Notes: This is a feasibility study only. The data collected were for use in estimating feasibility and not for investigating the association between exposure to diesel exhaust and lung cancer.

Reviewer: Susan Buchanan

Complete Title: Occupational Exposure and Lung Cancer risk: A Population-Based Case-Referent Study in Sweden. Am J Epidemiol. 2000 Jul 1;152(1):32–40. Gustavsson, P., Jakobsson, R., Nyberg, F., Pershagen, G., Jarup, L., Scheele, P.

Abstract: This case-referent study investigated the lung cancer risk from occupational exposure to diesel exhaust; mixed motor exhaust; other combustion products, asbestos, metals, oil mist, and welding fumes. All cases of lung cancer in males aged 40 to 75 years old among stable residents of Stockholm County, Sweden, were identified from 1985 to 1990. Referents were selected as a stratified (age, inclusion year) random sample. Information on lifetime occupational history, residency, and tobacco smoking was obtained from the study subjects or from next of kin. Response rates of 87% and 85% resulted in 1,042 cases and 2,364 referents, respectively. Occupational exposures were assessed by an occupational hygienist who coded the intensity and probability of each exposure. Risk estimates were adjusted for tobacco smoking, other occupational exposures, residential radon, and environmental exposure to traffic-related air pollution. For the highest quartile of cumulative exposure versus no exposure, the relative risk was 1.63 (95% confidence interval (CI): 1.14, 2.33) for diesel exhaust, 1.60 (95% CI: 1.09, 2.34) for combustion products, and 1.68 (95% CI: 1.15, 2.46) for asbestos. Dose-response analyses indicated an increase in lung cancer risk of 14% per fiber-year/ml for asbestos exposure. No increased risk was found for the other exposure factors. An overall attributable proportion of 9.5% (95% CI: 5.5, 13.9) was estimated for lung cancer related to diesel exhaust, other combustion products, and asbestos.

Methodology: The population included all men aged 40 to 75 years old who were residents of Stockholm County, Sweden, at any time between 1985 and 1990. All cases of lung cancer diagnosed in that time period were identified from the regional cancer registry. Controls were randomly selected from population registers and matched for age and year of inclusion. A postal questionnaire was sent to all study subjects and included information on lifetime occupational history, residential history, smoking habits and other risk factors for lung cancer. An industrial hygienist assessed the intensity and probability of exposure to occupational exposure factors for every subject on a case-by-case basis and based the assessment on personal contacts, personal experience, and reports of exposure levels specific for occupation. Nitrogen dioxide was used as an indicator for exposure to diesel exhaust.

The relative risks of developing lung cancer were estimated by unconditional regression. Smoking was controlled for. Environmental levels of nitrogen dioxide were used to estimate non-occupational exposure to air pollutants from road traffic. Indoor radon exposure was estimated using geographic data on ground levels of radon.

Scope of Work: To investigate the lung cancer risk from occupational as well as environmental exposures, using detailed individual exposure data. This paper focused on lung cancer risk in relation to seven occupational exposure factors: diesel exhaust, mixed motor exhaust, combustion products, asbestos, metals, oil mist, and welding fumes. Results regarding environmental exposures were published separately.

Sample Size: 1,042 cases and 2,364 controls

Industry Sector: General population

Major Limitations: Exposure estimates performed by only one industrial hygienist

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

"Slightly increased relative risks were observed in the highest estimated exposure to mixed motor exhaust and to intermediate exposure to diesel exhaust." (p. 6 of 14)

"Increased risks of lung cancer were noted in the highest quartiles of cumulative exposure to diesel exhaust, combustion products and asbestos. The risk associated with exposure to diesel exhaust was affected neither by adjustment for smoking habits nor by adjustment for exposure to combustion products and asbestos." (p. 6 of 14)

"A positive dose-response relationship was noted for diesel exhaust." (p. 7 of 14)

"The present findings add further evidence for an association between diesel exhaust and lung cancer" (p. 9 of 14)

Reviewer's Notes:

This is a study adding to the literature on the association between exposure to diesel exhaust and lung cancer. Typical biases in questionnaire studies were controlled for and risk estimates for lung cancer adjusted for smoking, radon exposure, and ambient nitrogen dioxide levels (as an indicator of road traffic air pollution).

Reviewer: Susan Buchanan

Complete Title: Executive Summary, Diesel Emissions and Lung Cancer: Epidemiology and Quantitative Risk Assessment. Health Effects Institute 1999.

Abstract: n/a

Methodology: Not given in executive summary

Scope of Work: (1) to review the epidemiologic data that form the basis of current quantitative risk assessments, (2) to identify data gaps and sources of uncertainty, (3) make recommendations about the usefulness of extending or conducting further analyses of existing data sets, and (4) make recommendations for the design of new studies that would provide a stronger basis for risk assessment. "It [the panel] was not charged to evaluate either the broad toxicologic or epidemiologic literature concerning exposure to diesel exhaust and lung cancer for hazard identification purposes, which has been done by others." (p. 1)

Sample Size: n/a

Industry Sector: n/a

Major Limitations: This was a limited evaluation of the literature.

Findings Directly Related to HOS (include page references):

Driver Health (General)

"At present, the railroad worker cohort study (Garshick et al. 1988), though part of a larger body of hazard identification studies, has very limited utility for QRA of lifetime lung cancer risk from exposure to ambient levels of diesel exhaust . . ." (p. 4)

"The investigators' analysis of the teamster data reported an exposure-response relation (Steenland et al. 1998) that may be useful for QRA; this relation will be better understood with further exploration of uncertainties and assumptions, particularly those relating to the reconstruction of past exposures and the selection of controls." (p. 4)

Reviewer's Notes: This summarizes the work of the Diesel Epidemiology Project of the Health Effects Institute (HEI) which set out to address the 4 issues listed above. It does not evaluate the evidence associating diesel exhaust with lung cancer, but it does comment on studies (Steenland and Garshick) reviewed for the HOS literature search in Part I.

Reviewer: Susan Buchanan

Complete Title: Mortality Associated with Sleep Duration and Insomnia. Kripke, D.F., Garfinkel, L., Wingard, D., Klauber, M., Marler, M. Arch Gen Psych 59. 131–136. 2002.

Abstract: Background: Patients often complain about insufficient sleep or chronic insomnia in the belief that they need 8 hours of sleep. Treatment strategies may be guided by what sleep durations predict optimal survival and whether insomnia might signal mortality risks. Methods: In 1982, the Cancer Prevention Study II of the American Cancer Society asked participants about their sleep duration and frequency of insomnia. Cox proportional hazards survival models were computed to determine whether sleep duration or frequency of insomnia was associated with excess mortality up to 1988, controlling simultaneously for demographics, habits, health factors, and use of various medications. Results: Participants were more than 1.1 million men and women from 30 to 102 years of age. The best survival was found among those who slept 7 hours per night. Participants who reported sleeping 8 hours or more experienced significantly increased mortality hazard, as did those who slept 6 hours or less. The increased risk exceeded 15% for those reporting more than 8.5 hours sleep or less than 3.5 or 4.5 hours. In contrast, reports of "insomnia" were not associated with excess mortality hazard. As previously described, prescription sleeping pill use was associated with significantly increased mortality after control for reported sleep durations and insomnia. Conclusions: Patients can be reassured that short sleep and insomnia seem associated with little risk distinct from comorbidities. Slight risks associated with 8 or more hours of sleep and sleeping pill use need further study. Causality is unproven.

Methodology: The Cancer Prevention Study of the American Cancer Society (CSPII) provided data from 1.1 million participants who completed health questionnaires in 1982. Survival or date of death was ascertained 6 years later. 32 covariates were entered into the models of sleeping duration and mortality risk.

Scope of Work: To explore whether sleep duration predicts mortality.

Sample Size: 636,095 men and 480,841 women

Industry Sector: General population

Major Limitations: n/a

Findings Directly Related to HOS (include page references):

Driver Health (General)

"Among both women and men, the best survival was experienced by those reporting a usual sleep duration of 7 hours." (p. 5 of 10)

" Reported sleep had to be less than 3.5 hours among women and less than 4.5 hours among men for the added risk associated with short sleep to exceed 15%." (p. 5 of 10)

"Comparison of the 32-covariate models with the simplified CPSII models and the less-controlled CPSI tabulations showed that most mortality risk associated with short sleep could be explained by comorbidities." (p. 6 of 10)

Reviewer's Notes: Short sleep duration of as low as 4.5 hours does not affect mortality. This study offers an opposing view to the studies showing adverse health effects of sleep deprivation.

Reviewer: Susan Buchanan

Complete Title: The relative importance of whole body vibration and occupational lifting as risk factors for low-back pain. K.T. Palmer, M.J. Griffin, H.E. Syddall, B. Pannett, C. Cooper, D. Coggon. Occup Environ Med 2003;60:715–721.

Abstract: Aims: To explore the impact of occupational exposure to whole body vibration (WBV) on low back pain (LBP) in the general population and to estimate the burden of LBP attributable to occupational WBV in comparison with that due to occupational lifting. Methods: A questionnaire including sections on WBV at work, LBP, and potential risk factors was mailed to a community sample of 22,194 men and women of working age. Sources and durations of exposure to occupational WBV were ascertained for the past week and personal vibration doses (eVDV) were estimated. Analysis was confined to subjects reporting exposures in the past week as typical of their work. Associations of LBP with eVDV, driving industrial vehicles, and occupational lifting were explored by logistic regression and attributable numbers were calculated. Results: Significant associations were found between daily lifting of weights greater than 10 kg at work and LBP, troublesome LBP (which made it difficult to put on hosiery), and sciatica (prevalence ratios 1.3 to 1.7); but the risk of these outcomes in both sexes varied little by eVDV and only weak associations were found with riding on industrial vehicles. Assuming causal associations, the numbers of cases of LBP in Britain attributable to occupational WBV were estimated to be 444,000 in men and 95,000 in women. This compared with an estimated 940,000 male cases and 370,000 female cases of LBP from occupational lifting. Conclusions: The burden of LBP in Britain from occupational exposure to WBV is smaller than that attributable to lifting at work.

Methodology: A postal survey was sent to 22,194 adults in Britain regarding exposure to vibration and health. Subjects were selected at random from patient lists of general practices and from members of the armed services randomly selected from pay records. Exposure to vibration was assessed by asking about driving or riding any of a checklist of vehicles. Duration of exposure was also assessed. Logistic regression was adjusted for non-occupational exposure to WBV.

Scope of Work: To assess the burden of LBP caused by exposure to WBV and to compare it with LBP caused by heavy lifting. Questionnaires were sent to general public and armed services in Britain.

Sample Size: 4,250 men and 3,061 women were included in the final analysis.

Industry Sector: n/a

Major Limitations: Exposure was assessed by questionnaire only. May have response bias; those with back pain or exposure to vibration were more likely to complete the survey.

Findings Directly Related to HOS (include page references):

Working Conditions (Environmental except sleeper berth)

Very weak association found between estimated vibration dose and presence of low back pain. “The data on WBV do not provide strong evidence to suggest a cause-effect relation (and do not distinguish the risks of sitting and driving from those of merely sitting).” (p. 717) “Use of industrial vehicles in general did not appear to confer an increased risk in men.” A significant association was found in women, although many fewer women had these exposures.

Reviewer’s Notes: Studies using populations of exposed workers instead of just the general population show stronger associations between WBV and low back pain. This may be due to the multiple possibilities for bias inherent in a cross-sectional survey of the general population.

Reviewer: Susan Buchanan

Complete Title: Impact of sleep debt on metabolic and endocrine function. Spiegel, K., Leproult, R., Van Cauter, E. Lancet 1999;354:1435–1439.

Abstract: Background: Chronic sleep debt is becoming increasingly common and affects millions of people in more-developed countries. Sleep debt is currently believed to have no adverse effect on health. We investigated the effect of sleep debt on metabolic and endocrine functions. Methods: We assessed carbohydrate metabolism, thyrotropic function, activity of the hypothalamo-pituitary-adrenal axis, and sympathovagal balance in 11 young men after time in bed had been restricted to 4 h per night for 6 nights. We compared the sleep-debt condition with measurements taken at the end of a sleep-recovery period when participants were allowed 12 h in bed per night for 6 nights. Findings: Glucose tolerance was lower in the sleep-debt condition than in the fully rested condition ($p < 0.02$), as were thyrotropin concentrations ($p<0.01$). Evening cortisol concentrations were raised ($p = 0.0001$) and activity of the sympathetic nervous system was increased in the sleep-debt condition ($p < 0.02$). Interpretation: Sleep debt has a harmful impact on carbohydrate metabolism and endocrine function. The effects are similar to those seen in normal aging and, therefore, sleep debt may increase the severity of age-related chronic disorders.

Methodology: Eleven healthy young men spent 16 nights in the clinical research center. For the first 3 nights, they spent 8 hours in bed; for 6 nights, they were in bed for 4 hours; and the last 7 nights, they were in bed for 12 hours. They were assessed for carbohydrate metabolism and hormonal profiles and compared sleepiness, sympathovagal balance, and saliva-free cortisol concentrations in all three conditions.

Scope of Work: To evaluate the metabolic and hormonal variables in people in whom sleep had been restricted and extended.

Sample Size: 11 healthy volunteers

Industry Sector: n/a

Major Limitations: Very small population. (n = 11) Limited population (healthy young men)

Findings Directly Related to HOS (include page references):

Driver Health (General)

"During the sleep-debt condition, responses were consistent with a clear impairment of carbohydrate tolerance." (p.1437)

"The normal rise in thyrotropin at night was strikingly decreased in the sleep-debt condition compared with that in the sleep-recovery condition . . ." (p. 1438)

"Based on the analysis of the concentrations of free cortisol in saliva, the rate of decrease of free cortisol concentrations between 1600 h and 2100h was about six times slower in the sleep-debt condition than in the sleep-recovery condition." (p. 1438)

"Therefore, although the primary function of sleep may be cerebral restoration, sleep debt also has consequences for peripheral function that, if maintained chronically, could have long-term adverse effects on health." "The metabolic and endocrine alterations seen during the sleep-debt condition therefore mimic some of the hallmarks of aging, which suggests that chronic sleep loss could increase the severity of age-related pathologies, such as diabetes and hypertension." (p. 1438)

Reviewer's Notes: Changes in metabolic function seen during sleep deprivation in this study are similar to that seen in patients with type 2 diabetes. Changes in cortisol levels with sleep deprivation are similar to that seen in normal aging.

Reviewer: Susan Buchanan

Complete Title: Short Sleep Duration Is Associated with Reduced Leptin, Elevated Ghrelin, and Increased Body Mass Index. Shahrad Taheri, Ling Lin, Diane Austin, Terry Young, and Emmanuel Mignot Plos Med. 2004 December; 1(3): e62.

Abstract: Sleep duration may be an important regulator of body weight and metabolism. An association between short habitual sleep time and increased body mass index (BMI) has been reported in large population samples. The potential role of metabolic hormones in this association is unknown. Methods and Findings: Study participants were 1,024 volunteers from the Wisconsin Sleep Cohort Study, a population-based longitudinal study of sleep disorders. Participants underwent nocturnal polysomnography and reported on their sleep habits through questionnaires and sleep diaries. Following polysomnography, morning, fasted blood samples were evaluated for serum leptin and ghrelin (two key opposing hormones in appetite regulation), adiponectin, insulin, glucose, and lipid profile. Relationships among these measures, BMI, and sleep duration (habitual and immediately prior to blood sampling) were examined using multiple variable regressions with control for confounding factors. A U-shaped curvilinear association between sleep duration and BMI was observed. In persons sleeping less than 8 h (74.4% of the sample), increased BMI was proportional to decreased sleep. Short sleep was associated with low leptin (p for slope = 0.01), with a predicted 15.5% lower leptin for habitual sleep of 5 h versus 8 h, and high ghrelin (p for slope = 0.008), with a predicted 14.9% higher ghrelin for nocturnal (polysomnographic) sleep of 5 h versus 8 h, independent of BMI. Conclusion: Participants with short sleep had reduced leptin and elevated ghrelin. These differences in leptin and ghrelin are likely to increase appetite, possibly explaining the increased BMI observed with short sleep duration. In Western societies, where chronic sleep restriction is common and food is widely available, changes in appetite regulatory hormones with sleep curtailment may contribute to obesity.

Methodology: All employees aged 30 to 60 yr of four state agencies in south central Wisconsin were mailed a survey on sleep habits, health, and demographics in 1989. Mailed surveys were repeated at 5-yr intervals. A stratified random sample of respondents was then recruited for an extensive overnight protocol including polysomnography at baseline. Collection of morning, fasted blood levels of leptin, insulin, ghrelin and adiponectin were added to the protocol in 1995. A 6-day diary of sleep duration was added as part of a protocol to assess daytime sleepiness after the initiation of the cohort study. Multiple regression was used to evaluate the relationship of age, sex, and BMI on hormones. Partial correlations adjusted for age, sex, and BMI were calculated for hormones, with and without control of other potential confounders. The relationships between hormones and sleep were evaluated using multiple linear regression after control for potential confounders including age, sex, BMI, SDB (sleep disordered breathing), and morningness tendencies.

Scope of Work: To investigate the associations among sleep duration (acute and habitual), metabolic hormones, and BMI in the population-based Wisconsin Sleep Cohort Study. Two key opposing hormones in appetite regulation, leptin and ghrelin, play a significant role in the interaction between short sleep duration and high BMI. Leptin is an adipocyte-derived hormone that suppresses appetite. Ghrelin is predominantly a stomach-derived peptide that stimulates appetite. Other mediators of metabolism that may contribute include adiponectin and insulin. Adiponectin is a novel hormone secreted by adipocytes and is associated with insulin sensitivity.

Sample Size: 1,024 participants in the overnight study and blood sample. 720 in the diary portion.

Industry Sector: General population

Major Limitations: Baseline response rate was 51%.

Findings Directly Related to HOS (include page references):

Driver Health (General)

"We found a significant U-shaped curvilinear relationship between average nightly sleep and BMI after adjustment for age and sex. The minimum BMI was predicted at 7.7 h of average nightly sleep. The most striking portion of the curve was for persons sleeping less than 8 h, where increased BMI was proportional to decreased sleep." (p. 4 of 11)

In the multiple regression model, there was a significant increasing trend in leptin for average nightly sleep duration. There was a significant decreasing trend in ghrelin with total sleep time. (Low leptin and elevated ghrelin are usually associated with increased appetite.) There was no significant correlation between sleep duration (acute or chronic) and serum adiponectin, insulin, and glucose.

"[These findings] also represent the first demonstration of a correlation between peripheral hormone levels and both self-reported (questionnaire and diary data) and polysomnographically determined sleep amounts in a general population sample." (p. 5 of 11)

"When controlling for BMI, we found no significant correlation between insulin, glucose, or adiponectin levels and various measures of sleep duration." (p. 7 of 11)

Reviewer's Notes:

Study shows association between sleep duration and obesity, and sleep duration and hormones which increase appetite. No association was found with sleep duration and glucose or insulin levels.

Reviewer: Susan Buchanan

Complete Title: Working Long Hours. White J, Beswick J. United Kingdom Health and Safety Laboratory. 2003.

Abstract: n/a

Methodology: Literature review. Literature searches were conducted by the HSE Information Centre search team. The team searched the following databases: OSH-ROM, RILOSH; HSELINE; CISDOC: NIOSHTIC2; Medline; Psychlit; EMED; and Healsafe. The key words used were: long working hours; working time; fatigue; health; safety; work-life balance; accidents; psychological effects; task; industry. Shiftwork was specifically omitted. In order to keep the review to a manageable size, it was decided to concentrate solely on articles relating to long working hours, and not those relating to shiftwork, and on literature from the last 10 years. Articles from academic journals as well as articles from health and safety related and other journals were retrieved. The articles included in this review were mostly selected on the basis of their abstract. The findings of the review reflect these constraints.

Scope of Work: To review the literature on the relationship between long working hours and fatigue, health and safety, and work-life balance outcomes.

Sample Size: n/a

Industry Sector: n/a

Major Limitations: n/a

Findings Directly Related to HOS (include page references):

Driver Health (General)

Several studies investigating 'karoshi' in Japan were reviewed. Karoshi refers to a syndrome of cardiovascular attacks attributable in part to the long-hours culture of the Japanese. Few other health effects were included in this write-up: one study assessing the effect of long hours on immunity and one showing higher rates of diabetes were mentioned.

"There appears to be a link between working long hours and cardiovascular disorder but several factors (e.g., existing medical conditions or insufficient sleep) may mediate this link."(p. 20)

"There appears to be evidence linking working long hours with poor lifestyle behaviors and other physical health problems, such as lowered immunity and diabetes mellitus." (p. 20)

"From the available evidence, there is sufficient reason to be concerned about a possible link between long hours and physical health outcomes, especially for hours exceeding 48 to 50 per week. However, samples were not very diverse, as much research seems to focus on men in Japan." (p. 20)

Reviewer's Notes: This literature review reinforces the notion that long work hours may contribute to risk of cardiovascular disease. However, other health effects of long hours were barely mentioned. Most of this extensive report was devoted to fatigue, performance, and lifestyle issues, not to health effects.

Reviewer: Peter Orris

Complete Title: *Diesel and Health in America: the Lingering Threat.* Schneider, C.G., Hill, L.B., Clean Air Task Force, Boston, MA, February 2005.

Abstract: The U.S. Environmental Protection Agency has issued regulations that will require dramatic reductions in emissions from new diesel vehicles starting in 2007—but only the new ones. These regulations, to be phased in over the next quarter century, apply only to new engines. The lifespan of the average diesel vehicle is nearly 30 years. Many diesels are driven over a million miles. Because of this longevity, we will be left with the legacy of pollution from dirty diesel vehicles for decades to come. Pollution from dirty diesels on the road now can be dramatically reduced using a combination of cleaner fuels, retrofit emission controls, rebuilt engines, engine repowerings, and accelerated purchase of new, cleaner vehicles. The Clean Air Task Force commissioned Abt Associates, to quantify the health impacts of fine particle air pollution from America's diesel fleet. Using this information, we were able to estimate the expected benefits—in lives saved—from an aggressive but feasible program to clean up dirty diesel buses, trucks, and heavy equipment across the United States. It then reviews the degree to which diesel vehicles increase the level of fine particle pollution in the air we breathe, and recommends reduction measures that will save thousands of lives each year.

Methodology: Collected available environmental particulate data, reviewed the literature as to health effects, modeled the amount of exposure from the current diesel truck fleet in the United States and calculated the human and economic costs of not putting in available protective technologies across the board.

Scope of Work: To review the relationship between diesel exhaust and health impacts on the population as a whole and estimate the human and economic costs of continued inaction with respect to utilizing available technology to reduce exposure.

Sample Size: n/a

Industry Sector: n/a

Major Limitations: Modeling exercise based on partial data allowing debate as to the magnitude of the quantitative conclusions reached.

Findings Directly Related to HOS (include page references):

Driver Health (General)

- Reducing diesel fine particle emissions 50% by 2010, 75% by 2015, and 85% by 2020 would save nearly 100,000 lives between now and 2030.
- Fine particle pollution from diesels shortens the lives of nearly 21,000 people each year. This includes almost 3,000 early deaths from lung cancer.
- Tens of thousands of Americans suffer each year from asthma attacks (over 400,000), heart attacks (27,000), and respiratory problems associated with fine particles from diesel vehicles. These illnesses result in thousands of emergency room visits, hospitalizations, and lost work days. Together with the toll of premature deaths, the health damages from diesel fine particles will total $139 billion in 2010.
- Nationally, diesel exhaust poses a cancer risk that is 7.5 times higher than the combined total cancer risk from all other air toxics.
- In the United States, the average lifetime nationwide cancer risk due to diesel exhaust is over 350 times greater than the level U.S. EPA considers to be "acceptable" (i.e., one cancer per million persons over 70 years).
- Residents from more than two-thirds of all U.S. counties face a cancer risk from diesel exhaust greater than 100 deaths per million population. People living in eleven urban

counties face diesel cancer risks greater than 1,000 in a million—one thousand times the level EPA says is acceptable.

- The risk of lung cancer from diesel exhaust for people living in urban areas is three times that for those living in rural areas.

Reviewer's Notes: This literature review is consistent with the conclusion that increased weekly working hours and the probable concomitant increased exposure to diesel exhaust is likely to contribute to an increased risk of cancer. It is also consistent with the conclusion that this impact is likely mitigated by changes in cab and engine design currently incorporated in new vehicles.

FATIGUE EFFECTS REFERENCES REVIEW

SELECTION CRITERIA

The 25 references included in this part were derived from a total of 266 references included in comments on the advanced NPRM. Of the 266 references, 86 pertained to health effects and were passed on to Dr. Peter Orris for evaluation. The remaining 180 articles were rated on a scale of 1 to 4 for relevance, with 34 given a score of 1, 25 a score of 2, and the remaining 121, scores of 3 or 4. The most relevant (score of 1) 34 articles on performance, crash risk, and fatigue were selected for review, of which 25 could be obtained. Articles considered most relevant were those involving epidemiological studies of CMV crash risk or field studies of performance of commercial drivers in relation to fatigue issues such as daily and weekly hours, time of day, and short sleep, or studies of non-CMV drivers showing the effects of sleep loss and comparing sleep loss and alcohol impacts. In Part I, no crash studies were reviewed.

The reasons for not reviewing the remaining articles suggested by commentators included the following:

- The article was not published as a report of a recognized agency or in a peer-reviewed journal (e.g., a website only or popular magazine).
- The article was very general in nature (e.g., Sleep and Circadian Disturbances in Shift Work: Strategies for Their Management).
- The article was not sufficiently relevant to the task of CMV driving and to the issue of fatigue and health (e.g., A Photograph-Based Study of the Incidence of Fatal Truck Underride Crashes in Indiana; Census of Fatal Occupational Injuries Summary; Effects on Performance of High and Low Energy-Expenditure During Sleep Deprivation).

EXECUTIVE SUMMARY

Fatigue, Time of Day, and Performance

The impacts of shift schedule on subjective fatigue and performance were measured in a field study by Williamson et al. (2004). In addition to permanent day shift and night shift drivers, drivers working alternating weeks of day and night shifts participated in the study. Fifty-four drivers were measured repeatedly over a 2-week period. Actigraph data were also collected to provide objective measures of the timing and quality of sleep. The researchers found that while the night shifts made drivers feel more tired than day shifts, they did not produce significantly poorer performance on tests of PVT and Mackworth Clock, "suggesting that night drivers can manage their fatigue." Over a typical workweek of five consecutive 10- to 12-hour shifts, there was a significant increase in subjective ratings of fatigue by all drivers.

Night shift drivers worked longer shifts than day shift drivers and spent much more of their working time driving than day shift drivers "which might predict that night shifts would be more tiring than day shifts." However, the authors suggest that night shift drivers may have performed as well as day shift drivers as they may be "especially tolerant of fatigue or skilled at managing fatigue" and because they organize their sleep differently (e.g., napping in the hours before their first shift of the week) which may partly explain how they could maintain performance. For example, the authors noted that night drivers "endeavored to capitalize on the sleep propensity influences of the circadian rhythm by getting as much sleep as they could as close as possible to the early morning circadian trough when sleep is most likely."

All drivers had restricted sleep (4 to 6 hours) and worked long hours (50 to 55 hours arranged in five 10- to 12-hour shifts), which the authors believe may have overshadowed any circadian differences. However, it could be argued this would be more likely to exacerbate them. They note a problem of missing data. Also all tests were done when the vehicle was stopped which may have re-alerted drivers. Other studies which have used performance measures that were integral to the driving task, such as lane tracking control and critical incidents, have found poorer performance at night, compared with during the day, most notably the U.S.-Canada study by Wylie et al. 1997, which compared different driving schedules as well as the study of long-haul single and team drivers by Dingus et al. 2001. Nonetheless the Williamson et al. (2004) findings are surprising given other studies where the PVT was sensitive to circadian effects (Dinges et al. 1997).

Scheduling Flexibility and Fatigue

Williamson et al. (2004) report further analysis of their 1996 study (Williamson et al. 1996) in which 27 commercial drivers participated in each of three work practices: staged trip driving (two drivers from different points of origin meet mid-trip and exchange loads), flexible trip driving (single driver, trip scheduled without reference to HOS regulations) and single trip driving (single driver, within HOS regulations). A range of fatigue measures were used including performance tests, physiological and subjective measures. The authors found that "a 10–12 hour trip is tiring no matter how the work is organized, and that the effects of accumulated fatigue may overshadow the effects of fatigue on a single 10–12 hour trip."

"Differences between driving types were not sufficient to account for changes in fatigue or performance in this study. All drivers reported more fatigue over the trip, but not all drivers showed poorer performance. It seems that the 12-hour trip is relatively immune to any effects of differences in work practices. It is possible that studying such relatively short trips will not provide clear findings . . . It is certainly noteworthy that flexible trips produced no worse an outcome than either of the other two ways of doing the same trip. In fact, a more exhaustive evaluation of flexibility, where drivers have the opportunity to learn about manipulating the timing of work and rest during several trips, might reveal that flexibility is of benefit in managing fatigue. . . . It should be noted, however that flexible drivers did tend to select work-rest schedules which were quite similar to the regulated working hours. It would be interesting to determine whether this similarity persists when the trip is longer."

Decrements in performance may be more detectable when driving performance is measured as opposed to the alerting situation of stopping to carry out a special performance test as was done in this study.

The findings of this study suggest that drivers do not make use of flexible schedules in a manner that reduces fatigue. Fatigue management programs may assist, especially if not only drivers but also dispatchers and managers are involved. A limitation is suggested by the Williamson study that indicates little difference in fatigue effects on different schedules if sleep is restricted and hours are long.

Regulated and unregulated HOS regimes were also compared using survey data by Hartley (1999). The Hartley et al. (1996) study on the impact of fatigue on heavy vehicle drivers in Western Australia (where there are no HOS regulations), was compared with Williamson and Feyer's 1992 study, which contained a comparable survey of drivers working under HOS in the eastern states. Drivers whose hours were not regulated were no more likely to exceed the HOS regulations that the drivers for whom those regulations were enforced. Drivers whose hours were not regulated were less likely to consider fatigue a problem than those whose hours were regulated. This may be due to less fatigue or to less awareness of the association of fatigue with poorer performance and increased crash risk. The authors list the following problems with HOS:

- HOS prescribe what a driver should be capable of doing (i.e., no flexibility).
- HOS regulations do not inform organizations about fatigue and safety.
- HOS regulations permit no discretion for different freight tasks and environments.
- HOS do not take account of the influence of the driver's circadian cycle.
- HOS regulations take no account of time zone changes.
- HOS may restrict access to sleep.
- There is no commercial incentive to restrict driving to HOS.

The numerous factors affecting fatigue and the difficulty of regulating hours of work to minimize it are discussed by Moore-Ede and Schlesinger (2005). They argue that risk relating to work and rest hours is multi-factorial and that simplistic regulations based on only one or two factors have limited value in minimizing this risk. Over 30 factors that determine level of sleepiness and fatigue-related accident risk are listed, with the most important being circadian phase followed by the number of consecutive hours spent continuously awake since the previous sleep episode. Other important factors are the length of the sleep episode, the quality of sleep, job workload, and moment to moment stimulants or depressants of alertness. The authors use two case studies to illustrate the problem with the current (11-hour driving) HOS regulations. In particular, they note the disincentive for drivers to take a nap when they are tired as daytime naps are only allowed to be excluded from a driver's hours on duty in certain situations when the nap is followed by driving, which is in turn immediately followed by an extended period of rest. The authors suggest that the efficacy of "alternative, less punitive, risk management strategies based upon the science of fatigue management" should be demonstrated to provide the basis of HOS regulation. The authors suggest alternative paradigms to the current work-rest regulations: fatigue management programs, fatigue risk models, alertness monitors.

Long Weekly Hours and HOS Violations

A number of studies have shown that despite the lengthy hours allowed by HOS regulations (60 hours in 7 days or 70 hours in 8 days), significant numbers of drivers work even longer. Beilock et al. (1995) use self-reported data to estimate the frequency of HOS violation-inducing schedules for a sample of 498 long-distance drivers. Twenty-six percent of the drivers, assuming average legal speed limits of 55 mph, were found to have violation-inducing schedules. Drivers most likely to have these schedules included solo drivers, drivers hauling refrigerated loads, regular route drivers, and those with longer current trip distances. The findings indicate that the very large majority of long-distance drivers have more than 40-hour work weeks (82%, assuming average maintained speeds of 50 mph), and extremely lengthy work weeks are common. For example, assuming 50-mph average maintaining speed, half the drivers work more than 65 hours weekly and one-quarter work over 81 hours.

Hertz et al. (1990) found for 130 long-haul tractor trailer drivers that at "assumed trip speeds of 40 mph and 50 mph, 90% and 51% of the drivers, respectively, were in violation of the hours of service rules by more than one hour."

Long Hours, Time of Day, and Crash Risk

Studies of the impact of long hours and time of day on crash risk are methodologically challenging for a number of reasons. First, the distribution of trip lengths is such that there are more 4-hour trips than 8-hour or 12-hour trips. Consequently, there will be more crashes associated with 4-hour trips than with 12-hour trips. This is a different issue from the risk per 4-hour trip or per 12-hour trip. Thus, it is important to control for exposure in order to determine per trip risk. Secondly, time of day and long hours both impact fatigue, and it is difficult to separate these impacts. Campbell (2002) reports that more than 25% of the accidents occurred in the first hour, and two-thirds in the first 4 hours, and that "only about 4 percent of all medium and heavy truck drivers involved in a fatal crash reported driving more than 8 hours at the time of the accident." The authors note that this pattern is driven "by exposure, not risk" as the "nature of the exposure distribution will always keep the number of accidents after many hours driving a small proportion of the total, even with dramatic increases in risk with hours driving." When differences in exposure were considered the authors found the following:

1. "The relative *risk* of fatigue given involvement in a fatal accident follows the circadian rhythm."
2. The relative *risk* of fatigue given involvement in a fatal accident "gradually increases during the first 8 hours, doubles during the ninth hour and is higher by a factor of 6 by the 12th hour."

Lin et al. (1994) formulated an elapsed time-dependent logistic regression model to assess the safety of motor carrier operations. The data were obtained from a national less-than truckload firm that operated coast-to-coast with no sleeper berths. The total number of observations used for modeling was 1,924 cases, of which 694 were accidents and 1,230 were non-accidents. The model "estimates the probability of having an accident at time interval, *t*, subject to surviving (i.e., not having an accident) until that time." The model was then tested with data from trips involving and not involving crashes from trucking company operations. Analysis showed that driving time had the strongest direct effect on crash risk.

Accident risk increased "significantly after the 4 hr, by approximately 50 percent or more, until the 7th hr. The 8th and 9th hr show a further increase, approximately 80 and 130 percent higher than the first 4 hr." Drivers with more than 10 years of driving experience had the lowest accident risk.

Daytime driving, particularly around noon, was associated with significantly lower risk of an accident and was defined as the baseline. The accident risk of driving between 4:00 and 6:00 p.m. was significantly higher (approximately 60% higher) than that of the baseline. This was attributed to two effects: evening rush hour and reduced alertness because of a low circadian period for some drivers. The accident risks from midnight to 2:00 a.m., 6:00 to 8:00 a.m., and 8:00 to 10:00 p.m. were significantly higher than during the baseline. Two periods involve night driving; the other involves part of the dawn period. Rest breaks, particularly those taken before the 6th or 7th hr of driving, appeared to lower accident risk significantly for many times of day.

Park et al. (2005) used pre-existing crash data from the 1980s and measurements from the Driver Fatigue and Alertness Study (DFAS) conducted in the mid-1990s. The total sample size was 5,050 drivers (i.e., 954 accident-involved drivers and 1,506 non-accident drivers in 1984; 887 accident drivers, and 1,604 non-accident drivers in 1985). The research appears to use a larger data set but similar methods to the Lin et al. study described previously. The study explores "whether a more detailed examination of time of day of driving, particularly over multiple days, indicates associations with crash risk." Night and morning driving and irregular schedules with primarily night and early morning driving, have significantly elevated crash risk of 20 to 70%, 30 to 80%, respectively, compared with daytime driving.

A case-control approach was used in New Zealand to determine the effect of work schedule variables on crash risk (Frith 1994). A 'case' group of drivers and heavy vehicles involved in crashes (1988 to 1990) were compared with a 'control' group of drivers and vehicles (1992 to 1993). The crash-involved drivers were 2.6 times more likely, as compared with non-crash involved drivers, to have driven 8 or more hours since the last compulsory 10-hour off-duty period (as recorded in the log book). However, no other scheduling variables were found to be associated with crash risk. Drivers involved in crashes tended to be younger than control drivers.

Once trip length is controlled for exposure, three crash studies show an increase in crash risk with hours of driving. Campbell (2002) concludes that the relative *risk* of fatigue given involvement in a fatal accident "gradually increases during the first 8 hours, doubles during the ninth hour and is higher by a factor of 6 by the 12th hour." Lin et al. shows that "accident risk increases significantly after the 4 hr, by approximately 50 percent or more, until the 7th hr. The 8th and 9th hr show a further increase, approximately 80 and 130 percent higher than the first 4 hr." Frith (1994) shows crash involved drivers to be 2.6 times more likely than non-crash involved drivers to have driven 8 or more hours.

With respect to hours driving and crash risk, these studies are consistent with earlier studies by Jones and Stein (1985) and Harris (1978). Using a case-control approach to examine the relative risk associated with long hours of driving, Jones and Stein (1987) found that tractor-trailer drivers who drove in excess of 8 hours, who violated log book regulations, and who were aged 30 and younger had an increased risk of crash involvement. In particular, the relative risk of crash involvement for drivers who reported a driving time in excess of 8 hours was almost twice (i.e., almost 100% higher) that for drivers who had driven fewer hours. Lin et al. 1994 found a 50% increase in risk after 4 hours of driving. In samples of dozing driver and single-vehicle crashes, Harris (1978) found that the changeover to more accidents than expected from fewer accidents than expected, occurred after about 5 hours of driving.

With respect to time of day of driving, Park et al. found that night and morning driving and irregular schedules with primarily night and early morning driving, have significantly elevated crash risk of 20 to 70%, 30 to 80%, respectively, compared with daytime driving. Lin et al. found some association with time of day. However, as noted by the authors, there was no control for exposure, hence the finding that the highest accident risk occurred between 4:00 and 6:00 p.m., peak hour with respect to traffic volume.

Time of day was controlled for exposure in the earlier study reported by Harris (1978). In a sample of single-vehicle crashes, the circadian effect was evident as 46% of the accidents occurred between midnight and 0800, almost "2.5 times as many as would be expected from the exposure data (19%). In a sample of "dozing driver" crashes, approximately 70% occurred between midnight and 0800. In contrast, approximately 25% of the accidents for the multi-vehicle crash sample occurred between midnight and 0800.

Time of day of driving has also been shown to impact crash risk of passenger car drivers. When exposure is accounted for, as it has been in three studies in different countries, of single-vehicle passenger car crashes, without alcohol involvement, a very strong association with time of day is found, with 13 to 25 times the risk of a crash per mile driven in the 2:00 to 4:00 a.m. period as compared with during typical working hours (see Smiley 2002 for a summary).

The effect of cumulative shifts in a sequence on crash risk has received little attention. One study by Jovanis and Kaneko (1990) examines this through an analysis of carriersupplied accident and nonaccident data for a 6-month period in 1984. The data were obtained from a "pony express" type operation, which operates coast to coast with no sleeper berths. Cluster analysis was used to identify nine distinct patterns of driving hours over a 7-day period. The driving patterns of drivers who had an accident on the 8th day were compared with drivers who had no accident on the 8th day. An increased crash risk was found for night but not day drivers after 3 to 4 days of driving.

Industrial shift schedules are typically more rigid than CMV driver schedules and studies using these are helpful in illuminating risks associated with various shift features. In a meta-analysis, Folkard and Lombardi (2004) examined studies of injuries and accidents which occurred in industrial settings and related them to the time of day; to the point within the shift system that they occurred; and to the shift features such as type of shift, length of shift, and number of successive shifts. (There were about 20 studies of accident and injuries referenced, and only a sub-sample of relevant studies could be used for each analysis.) There was a highly significant main effect of shift, in that risk increased by 18.3% on afternoon shifts and by 30.4% on night shifts relative to the morning shift.

There was also a consistent trend in accident risk over four successive nights. On average, risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night. Although the effect was not significant, there was also increased risk, though to a lesser degree, associated with successive day shifts. Risk was about 2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift. These findings are consistent with the Jovanis and Kaneko (1990) findings for truck drivers, in that cumulative shifts at night had a greater impact on crash risk than cumulative shifts worked during the day.

Folkard and Lombardi found that risk also increased with the length of the shift. Relative to 8-hour shifts, 10-hour shifts were associated with a 13.0% increase, and 12-hour shifts with a 27.5% increase in risk. These findings are also consistent with findings for CMV drivers, showing increases in crash risk after work exceeds 4 or 5 hours.

Sleep Restriction and Performance

A number of studies have shown that CMV drivers, especially long-haul drivers suffer from sleep restriction and thus the impact of sleep restriction on performance is a concern. Van Dongen et al. (2003) studied effects of chronic and total sleep restriction on cognitive performance and found that "chronic restriction of sleep periods to 4 h or 6 h per night over 14 consecutive days resulted in significant cumulative, dose-dependent deficits in cognitive performance on all tasks." Lapses in behavioral alertness and reductions in working memory performance in the 4 h condition reached levels equivalent to those observed after 2 nights without sleep. After 14 days of sleep restriction, cognitive throughput performance was equivalent to that observed after 1 night without any sleep. The authors note that the study results do not support the notion of "core" and "optional" sleep."

Belenky et al. (2003) viewed the core versus optional sleep issue slightly differently. They found that 7 days of sleep restriction degraded psychomotor vigilance performance in a sleep-dose dependent manner. With mild to moderate sleep restriction (7 and 5 hours time in bed), performance initially declined and, after a few days, appeared to stabilize at a lower-than-baseline level for the remainder of the sleep restriction period. In contrast, with severe sleep restriction (3 hours time in bed) performance declined continuously across the sleep restriction period, with no apparent stabilization of performance. Thus the 5 to 7 hours time in bed might be considered "core" sleep, in that performance stabilized, but was not at a level to maintain maximum performance. Three days of recovery sleep did not restore performance to baseline levels for subjects with mild to moderate sleep restriction (5 or 7 hours time in bed).

Lenne et al. (1997) looked at the effects of sleep deprivation, time of day, and driving experience on driving simulator performance. Lane position and speed variability were significantly higher following sleep deprivation. Circadian effects were shown in that performance steadily improved across the day between 0800 and 2000, after both normal sleep and sleep deprivation. Inexperienced drivers had higher reaction times than experienced drivers in both sleep-deprived and non-sleep deprived conditions."

The results of these studies suggest that there are cumulative performance consequences to limiting sleep to even as much as 6 hours per day, and that the effects of sleep deprivation may be more for inexperienced drivers.

Sleep Restriction, Time of Day, and Crash Risk

NTSB (1995) focused on the sleep patterns of the 96 hours preceding 107 single-vehicle heavy truck crashes in which the driver survived. Fifty-eight percent of the crashes were fatigue-related. Fatigue was considered a probable cause of the crash if the driver was estimated to have been on duty for more than 15 consecutive hours (the current legal limit), and if the driver's performance involved non-professional, irrational actions such as failure to brake or make appropriate steering maneuvers. A statistical analysis determined that the most important measures predicting a fatigue-related crash in this sample were the "duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the crash and the split-sleep patterns."

Studies described above indicate the negative effect of restricted sleep on performance. The NTSB study provides evidence that the performance changes resulting from restricted sleep can lead to crashes.

Fatigue, Sleep Restriction, and Crash Risk

Kecklund et al. (1999) examined 79 rail crashes, finding that approximately 17% were potentially related to fatigue or sleepiness. Indicators of suspected fatigue were considered to be present when one of the following three criteria appeared in combination with the fourth criterion:

- "The driver admitted or the investigator observed fatigue.
- Time of the accident (between 3:00 a.m. and 6:00 a.m.).
- Lack of sleep (less than 5 hours sleep) or a shift being preceded by a brief period of off-duty time (less than 11 hours).
- Accidents or incidents characterized by missed signals, lack of attention or loss of memory. It is known that this type of event is frequently triggered by fatigue. "

Only 4% of the accidents were fatigue related according to first criterion. However, this figure rose to 17% if all criteria were applied. While the majority of accidents occurred during the first 3 working hours, the authors note that length of trip was not controlled for exposure, and that the sample was small.

"The statistically significant analysis determined that the most important measures in predicting a fatigue-related accident in this sample are the duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep patterns."

Rail accidents, like truck accidents associated with fatigue, are characterized by non-performance and are related to time of day and restricted sleep. In less than one-quarter of the crashes did the engineer admit fatigue, suggesting only a small number of police reports indicate fatigue as the cause.

Alcohol vs. Prolonged Wakefulness

Arnedt et al. (2001) compared effects of alcohol with those of prolonged wakefulness on a simulated driving task. They found that performance following 19 and 22 hours of wakefulness (measured at 0230 and 0500) was equivalent to 0.05 and 0.08% BAC, respectively (measured during the day).

Roehrs et al. (2003) looked at the effects of sleep loss (0, 2, 4, and 8 hours of sleep loss) as compared with those of ethanol ingestion in 32 adults (ages 21 to 35). "The study was conducted in a mixed design with a between-subject factor, ethanol or sleep loss, and a within-subject factor, dose of either ethanol or sleep loss." The authors found that "sleep loss was more potent than ethanol in its sedative effects but comparable in effects on psychomotor performance. Ethanol produced greater memory deficits, and subjects were less aware of their overall performance impairment."

These two studies provide an appreciation of the impact of sleep loss in terms of the effects of alcohol, the effects of which on crash rates are well known. These studies suggest that CMV drivers working long hours after restricted sleep may be as impaired with respect to driving performance as drivers at the legal limit of alcohol.

Fatigue, Drugs, and Crash Risk

National Transportation Safety Board (NTSB) (1990) found "Thirty-three percent of the fatally injured drivers in 182 accidents tested positive for alcohol and other drugs of abuse." In approximately 8 of the 168 cases, urine samples were used to detect drugs of abuse. In the remainder of the 168 cases, blood samples were used at NTSB's sensitivity thresholds, which have substantially lower cutoff concentrations than the DOT drug testing regulations, making it more likely that positive test results would be found. A concern is whether the levels found indicate behavioral impairment due to the drug, or merely its presence. This is because presence can be detected in blood many hours after consumption, and in urine, days after consumption, in many cases long after effects on behavior can be detected. Alcohol/drugs positive results were more likely to be present on or after the weekend, and were no more likely to be found in fatigued drivers than in drivers not so designated.

The authors found that there was a strong association between violation of the federal HOS regulations and drug use. In addition, there was a significant relationship between drug positive test results and a shipment deadline for the load being carried. However, some of the drugs considered in this study are stimulants, which have been demonstrated to improve performance. The presence of an illegal drug cannot be considered as "impairing" unless there is evidence in the performance testing literature that the drug in the quantity found actually does impair performance.

Impact of System Issues on CMV Driver Fatigue

Virtually all studies of fatigue focus on the driver; few studies have looked at fatigue from a system perspective. One such study is by Braver et al. (1999) who looked at the role of shipper demands. Dispatchers were interviewed and reported that shippers rarely requested tight delivery schedules. However, there is a possibility that dispatchers may have responded to questions about tight delivery schedules according to typical driver work schedules rather than HOS regulations. In particular, the authors note, that the study "did not attempt to quantify how a dispatcher defined 'more than enough time,' 'just enough time,' or 'not enough time' to pickup and deliver." The majority of dispatchers said that time allotted per shipment for non-driving duties was up to the driver. Of those giving a quantitative estimate, most expected 2 to 4 hours. Drivers were interviewed and approximately 20% reported penalties from their motor carriers for late deliveries.

At the conference, Truck Safety: Perceptions and Reality, the attendees concluded that current HOS regulations in Canada and the United States 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 group also felt that low driver wages and lack of empowerment compelled drivers to drive longer hours without necessary rest (Saccomanno et al. 1995).

The above documents consider broader system issues versus individual trucker decisions. The Braver et al. study is limited in not defining "tight delivery schedules." A possible indicator of this is the dispatcher's estimate of time required for trucker's other duties of 2 to 4 hours. It would be interesting to compare dispatcher, driver, and fatigue expert opinions on what constitutes an appropriate delivery schedule.

Additional References

Dinges, D.F., Pack, F., Williams, K., Gillen, K.A., Powell, J.W., Ott, G.E., Aptowicz, C., and 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): 267–7.

Smiley, A. Chapter 6: Fatigue and driving. In *Human Factors and Traffic Safety*, Paul Olson and Robert Dewar (eds.), Lawyers & Judges Publishing Company, Tucson, Arizona. 2002.

REFERENCE SUMMARIES

Reviewers: Dianne Davis, Alison Smiley

Title: Arnedt, J.T., Wilde, G.J.S., Munt, P.W., and Maclean A.W. "How do prolonged wakefulness and alcohol compare in the decrements they produce on a simulated driving task?" (2001*). Accident Analysis and Prevention,* Vol. 33, 337–344.

Abstract: This report looks at a comparison of the effects of alcohol with those of prolonged wakefulness on a simulated driving task. Eighteen males (18 to 35 years old) with BACs of 0.00, 0.05 and 0.08% drove a simulator for 30 minutes. Dependent measures included subjective sleepiness before and after the driving task as well as simulator measures (e.g., tracking, speed deviation, etc.). Tracking variability, speed variability and off-road events increased with BAC. In contrast, speed deviation (calculated as the deviation from the speed limit) decreased as a result of subjects driving faster. With increased BAC, ratings of sleepiness increased and were higher following the driving task. The authors compared the results of this study with a previous study by Arnedt and Maclean (1996), examining simulated driving performance during one night of prolonged of wakefulness. They found that "mean tracking, tracking variability, and speed variability 18.5 and 21 h of wakefulness produced changes of the same magnitude as 0.05 and 0.08% blood alcohol concentrations, respectively." In addition, they found that alcohol consumption produced changes in speed deviation and off-road occurrences of greater magnitude than the corresponding levels of prolonged wakefulness.

Methodology: Eighteen males between 19 and 35 years old, who met the inclusion criteria (e.g., neither extreme morning nor evening type) were recruited for this study at Queen's University in Kingston, Ontario. On the nights before the first experimental day and for the duration of the study, subjects were instructed to go to bed between 2300 and 0100 and to get up between 0700 and 0900. The Stanford Sleepiness Scale (SSS) and a Modified Stanford Scale (MSS) were used as the subjective dependent measures for the study. Performance was assessed using a York Driving Simulator. A variety of dependent measures were collected using the simulator such as speed deviation, off-road incidents, etc. Subjects were given a training session prior to the start of the experiment to orient them to the driving simulator as well as other aspects of the study. They were then informed of their condition allocation (0.00, 0.05, and 0.08% BAC) and underwent all the three test conditions at the same time of day either 1400, 1700 or 2000. Experimental days consisted of brief training sessions to re-familiarized subjects with the driving simulator, followed by consumption of drinks mixed so that they would attain peak BACs of 0.0, 0.05 or 0.08%. Subjects were given one-half hour to ingest the drinks, and at 30 minutes post-ingestion, completed the SSS and the MSS and then drove the simulator for 30 minutes. The scales were also completed after the 30-minute simulator task. Subjects in Arnedt and Maclean's (1996) study underwent one night of prolonged wakefulness and drove on the driving simulator at 2400, 0230, 0500, and 0730. For 0.05 and 0.08% BAC, the most comparable test times in the Arnedt and Maclean (1996) study were 0230 (18.5 h of wakefulness) and 0500 (21 h of wakefulness), respectively.

Scope of Work: Comparison of effects of alcohol with those of prolonged wakefulness on driving.

Sample Size: 18 males (students) between 19 and 35 years of age (Note: Report does not indicate the number of subjects in Arnedt et al.'s (1996) comparison study).

Industry Sector: n/a

Major Limitations: The driving situations were limited to situations in which there was no other traffic present. The authors noted "had drivers been exposed to the perceptual and judgment demands of dealing with the greater hazards created by the presence of other traffic, it is possible that driving performance would have differed under prolonged wakefulness and alcohol conditions."

Findings:

1. ". . . wakefulness prolonged by as little as 3 h can produce decrements in the ability to maintain speed and road position as serious as those found at the legal limits of alcohol consumption."
2. The ratings of subjective sleepiness increased as alcohol dosage increased for the SSS and Factors 1 ('an energic or activating factor') and 2 ('related to consciousness, sleepiness and a loss of control over remaining awake') of the MSS. Subjects rated themselves as more sleepy after the driving task than before on each of these scales. No significant time-of-day effects were found for the subjective sleepiness measures.
3. With increased alcohol dose tracking variability, speed variability and number of off-road accidents increased. Speed deviation from the posted speed decreased as subjects drove faster.
4. Performance within the 30-minute driving period declined overall but only reached statistical significance in the case of tracking variability.
5. Time-of-day effects were largely absent, expect for speed deviation, which was lowest at 1700 relative to the other two test times.
6. "Performance following 19 and 22 h of wakefulness was equivalent to 0.05 and 0.08% BAC, respectively."
7. "Alcohol produced a more marked increase in speed than prolonged wakefulness, with a statistically significant difference between 0.08% BAC and the 05:00 h test time (21 h of wakefulness) but not the 07:30 h test time" (23.5 h wakefulness).
8. "The frequency of off-road occurrences was significantly greater in the 0.08% BAC condition than in the 05:00 h test time" (21 h of wakefulness) but not significantly different from the 07:30 h test time (23.5 hr wakefulness).
9. The study raised important issues "regarding driving after consuming alcohol at times of increased physiological sleepiness, namely between the 23:00–07:00 and 14:00–17:00 h" time periods as fatigue-related accidents are more likely to occur during these peak times for sleepiness.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 341, *". . . performance following 19 and 22 h of wakefulness was equivalent to 0.05 and 0.08% BAC, respectively."*

p. 341, *". . . driving performance was in a number of respects, affected similarly by prolonged wakefulness and by alcohol. With increasing time awake and increasing blood alcohol level, subjects tracked increasingly to the left of the center of the lane . . .), and their tracking variability . . . and speed variability . . . increased)."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Beilock, R. "Schedule-induced hours-of-service and speed limit violations among tractor-trailer drivers" (1995*). Accident Analysis and Prevention,* Vol. 27, No. 1, 32–42.

Abstract: This objective of this study was to determine the frequency of "schedule-induced hours-of-service rules (HSR) and/or speed limit violations by drivers of tractor-trailers by estimating the tightness of driver schedules over a specific trip." The authors use self-report data to estimate the frequency of violation-inducing schedules for a sample of 498 long-distance drivers. Twenty-six percent of the drivers, assuming average legal speed limits of 55 mph, were found to have violation-inducing schedules. Drivers most likely to have these schedules included solo drivers, drivers hauling refrigerated loads, regular route drivers, and those with longer current trip distances.

Methodology: Drivers were interviewed at Florida Agricultural Inspection Station about their current trip (e.g., origin, location of next pick-up/drop, time/date for pick-up/drop, number of miles over previous 7 days, participation of co-driver). The authors developed an index of schedule tightness (DRVSPD) which consisted of the "average speed a vehicle would need to maintain to reach the next destination without being late and with the driver obeying the driving times mandated by HSR." Previous driving time was "estimated by determining the time required to complete the driver-reported mileage driven over the previous seven days." In the analysis, three scenarios were examined assuming average road speed limits: 55 mph, 60 mph, and 65 mph. Weekly driving time was estimated by assuming an average speed, and then determining the driving time necessary to cover the driver's weekly mileage. While non-driving tasks (e.g., vehicle inspections) are an integral part of work for most drivers, the drivers in the sample were not questioned regarding non-driving work hours, to avoid raising their apprehension by asking too many questions related to HSR.

Scope of Work: An analysis of schedule-induced HSR and/or speed limit violations by drivers of tractor trailers.

Sample Size: Schedules of 498 long-distance drivers

Industry Sector: Long-distance truck drivers

Major Limitations: The authors note that the potential for response bias is always present when determining the incidence of any illegal activity. While the study relied heavily on information from questioning truck drivers, the authors employed measures to mitigate the response bias problem (e.g., limited their questions).

Findings:

1. Depending on the average speed limit scenario (i.e., 55, 60, 65 mph), between 17% and 30% of the drivers were found to have violation-suspect schedules and between 14% and 26% had schedules sufficiently demanding to be also judged as violation-inducing." (Author's Note: For a schedule to be considered violation-suspect or violation-inducing, a minimum average trip speed must be attained or exceeded. Therefore, a violation-inducing schedule would also be considered to be violation-suspect.")
2. Using the 55 mph average speed limits, an estimated 26% of all drivers had violation-inducing schedules. Ignoring the 60- and 70-hour rules, 15% of the drivers would have had such schedules due to the demands of the current trip. For 13% of the drivers, neither the 60- nor the 70-hour rules could be adhered to without violating speed limits. For 1% of the drivers (15 + 13 − 26)/2, both the current trip and the 60- or 70-hour rules result in violation-inducing schedules." These findings suggest a lower incidence of violation than was found in the Hertz study.
3. "Solo drivers were more likely than team drivers to have tight schedules due to the current trip."

4. "Depending upon the average speed limit assumed, drivers with refrigerated loads were between 50% and 80% more likely than other drivers to have violation-suspect or violation-inducing schedules (differences statistically significant at the .01 or .05 levels).
5. "For all three average speed limits, drivers for regular route carriers were significantly more likely than drivers on irregular routings to have violation-suspect schedules (at the .01 or .05 levels).
6. Longer current trip distance was positively correlated with tight schedules. Drivers with current trips over 1,000 miles were between five and seven times more likely to have violation-inducing schedules than were drivers with trips not over 500 miles.
7. "Assuming the average roadway traveled has 55 mph speed limits, over a quarter of all drivers must violate HSR or speed limits."
8. There is a trade-off between speed and driving time. "For example, at 45 mph average speed the average driver must drive 51 hours per week, compared with 38 hours if 60 mph is averaged. "
9. The authors present the estimated mean total weekly work hours for various assumed average speeds, as well as the work hours at each quartile. A very large majority of long-distance drivers have more than 40-hour work weeks (82%, assuming average maintained speeds of 50 mph). Assuming 50 mph average maintained speed, half the drivers work more than 65 hours weekly and one-quarter work over 81 hours.

Findings Directly Related to HOS (include page references):

Driver Duration

p. 37, *"Depending upon the average speed limit scenario, between 17% and 30% of the drivers were found to have violation-suspect schedules and between 14% and 26% had schedules sufficiently demanding to be also judged as violation-inducing."*

p. 37, *"Using the 55 mph average speed limits, an estimated 26% of all drivers had violation-inducing schedules. Ignoring the 60- and 70-hour rules, 15% of the drivers would have had such schedules due to the demands of the current trip. For 13% of the drivers, neither the 60- nor the 70-hour rules could be adhered to without violating speed limits. For one percent of the drivers (15 + 13 − 26)/2, both the current trip and the 60- or 70-hour rules result in violation-inducing schedules."*

p. 39, *"There is a very strong and positive relationship between current trip distance and schedule tightness. For all three average speed limit scenarios, the simple correlation between DRVSPD and trip distance is positive (ranging between .31 and .35) and significantly different from zero at the .01 level… "For all average speed limit scenarios and for current rip, the 60/70 –hour rule, and total: the longer the journey, the greater the frequency of violation-suspect and violation-inducing schedules. In all cases, the differences are easily significant at the .01 level."*

p. 40, *"Depending upon the average speed limits assumed, drivers with current trips over 1,000 miles are between five and seven times more likely to have violation-inducing schedules than are drivers with trips not over 500 miles."*

p. 41, *"Assuming 50 mph average speed, the average driver works 58 hours in total and drives 46 hours weekly. Seventy-five percent of these drivers work over 49 hours and drive more than 39 hours per week. Half the drivers exceed 65 hours total work and, of that, drive over 52 hours. Finally, a quarter of the drivers work more than 81 hours and drive over 64 hours per week (which is not legal under HSR)."*

p. 41, *"The findings indicate that the very large majority of long-distance drivers have more than 40-hour work weeks (82%, assuming average maintained speeds of 50 mph), and extremely lengthy work weeks are common. For example, assuming 50 mph average* *maintaining speed, half the drivers work more than 65 hours weekly and a quarter work over 81 hours."*

p. 41, *"Solo drivers were found to have much higher frequencies of violation-suspect and violation-inducing schedules, than team drivers. Again assuming 55 mph average speed limits, 28% of the solo drivers, but only 11% of the team drivers, would have to violate HSR and/or speed limits to stay on schedule. Due to these differences, the analysis focused on solo drivers. Among solo drivers, groups with higher incidences of violation-inducing schedules were those driving longer trip distances, driving refrigerated loads, and driving regular route carriers."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Belenky, G., Wesensten, N.J., Thorne, D.R., Thomas, M.L., Sing, H.C., Redmond, D.P., Russo, M.B., and Balkin, T.J. "Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study" (2003*). Journal of Sleep Research,* Vol. 12, 1–12.

Abstract: The data reported in this study are a subset of data collected in a larger study analyzed and published as a U.S. Department of Transportation Report (Balkin et al. 2000; see Part I). This paper focuses on the findings for psychomotor vigilance task performance (PVT), sleep latency, and subjective sleepiness. According to the authors, of the measures taken in the larger study, the PVT was chosen for this paper because it was the most sensitive to the effects of sleep restriction and was the least subject to learning effects." The purpose of the study was to empirically determine the effects of 3, 5, 7 and 9 hours of sleep over 7 consecutive days on objective and subjective alertness and objective performance. In addition, the study looked at the extent to which 3 days of subsequent recovery sleep restored performance and alertness to baseline levels.

Methodology: Drivers had 3 days of orientation and baseline sleep in the laboratory before data collection commenced over 7 days of performance testing with 3, 5, 7, or 9 hours of sleep each night. The recovery period, that followed, lasted 4 days with 8 hours in bed each night. A wide variety of measures were utilized. Measures consisted of the PVT, the cognitive performance assessment battery, driving simulator tasks (e.g., lane tracking) as well as sleep latency, EMG, and sleepiness ratings. In addition to these measures, a number of health measures were taken (e.g., tympanic temperature, heart rate, and blood pressure).

Scope of Work: Study of effect of sleep restriction on performance.

Sample Size: Sixty-six CMV drivers (16 females, media age = 43 years; 50 males, mean age = 37 years)

Industry Sector: CMV drivers

Major Limitations:

- Study only looked at daytime driving.
- Recovery sleep was restricted to 8 hours.
- The trade-off for using a wide variety of measures was that the number of daily administrations for each particular measure was restricted—precluding evaluation of circadian rhythms in this study.
- Subjects were heterogeneous with respect to age, which may have contributed to error variance in performance measures.

Findings: (See Balkin et al. (2000) in Part I.)

1. "Seven days of sleep restriction degraded psychomotor vigilance performance in a sleep-dose dependent manner. With mild to moderate sleep restriction (7- and 5-hr time in bed [TIB]), performance initially declined and, after a few days, appeared to stabilize at a lower-than-baseline level for the remainder of the sleep restriction period. In contrast, with severe sleep restriction (3-hr TIB) performance declined continuously across the sleep restriction period, with no apparent stabilization of performance. Sleep augmentation (9-hr TIB) had no effect on performance over the 7-day experimental period."
2. Three days of recovery sleep did not restore performance to baseline levels for subjects with mild to moderate sleep restriction (5- or 7-hr TIB).

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 9, *". . . it appears that the inflection point (i.e., the minimum amount of nightly sleep required to achieve a state of equilibrium in which daytime alertness and performance can* *be maintained at a stable, albeit reduced, level) is approximately 4 hr per night. If less than 4 hr of sleep per night is obtained, daily decrements in performance capacity may be unavoidable – at least across a 7-day period of sleep restriction."*

p. 10, *"The present findings suggest that core sleep might best be considered as the minimum amount of sleep needed by the brain to achieve a state of equilibrium in which alertness and performance are maintained at a stable but lower-than-normal level. In this view, sleep durations that do not satisfy the core sleep requirement would, across days, result in continued degradation of alertness and performance relative to baseline, but degradation would not continue across days indefinitely—an asymptotic, stable level of reduced alertness and performance would eventually be achieved; and additional sleep (i.e., incremental increases in the duration of sleep beyond the core requirement) would produce correspondingly higher, and stable, levels of alertness and performance."*

p. 10, *"Following chronic, mild to moderate sleep restriction (5- or 7-hr TIB), 3 days of recovery sleep (8-hr TIB) did not restore performance to baseline levels."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Braver, E.R., Preusser, C.W., and Ulmer, R.G., "How long-haul motor carriers determine truck driver work schedules: The role of shipper demands." (1999). Journal of Safety Research, Vol. 30, No. 3, pp. 193–204.

Abstract: The objective of this research was to identify determinants of drivers' schedules. In particular, the study looks at the "role of shipper demands within the load scheduling decision chain for individual drivers, as reported by dispatchers working for long-haul motor carriers." Two hundred and seventy dispatchers participated in telephone interviews. Dispatchers' reasons for accepting or rejecting loads from shippers were based on revenue (75%), delivery deadlines (24%) and the HOS status of the nearest driver (9%). However, dispatchers reported that shippers ask for "sufficient time for drivers to adhere to both speed limits and hours-of-service rules." Dispatchers were asked how the "time required to make a particular trip was determined." Trip mileage was reported "as the key determinant of trip schedule assignments (58%)"; however, other factors were also considered, "including speed limits (27%) and past experience with particular routes (13%). The authors concluded that the results of the survey suggested that, "tight schedules cannot be attributed solely to shipper demands."

Methodology: Long-haul drivers were surveyed at weigh stations in Wyoming and Tennessee about job characteristics (e.g., size of carrier, penalties for late delivery), and asked to identify who arranged their current loads. Interviewers eliminated a number of drivers (e.g., those who worked for private or terminal-to-terminal carriers), to focus on "U.S long-haul motor carriers that make decisions concerning the acceptance or refusal of potential loads and that figure out driver delivery schedules based on a single truck, meeting the needs of an individual shipper for transport of a specific load." Interviews were conducted with 270 of the 309 dispatchers identified by drivers. Dispatchers were asked a number of questions: "how they figured the time necessary for trips; how often shippers imposed penalties for late deliverables; what percentages of shippers asked for just enough time, not enough time, or more than enough time to pick up and deliver loads; and what factors affected their decisions to accept or reject loads from customers. Dispatchers were also asked if they used any computer program to estimate the time necessary for trips," as these programs "can include criteria needed to comply with hours-of-service rules."

Scope of Work: Focus on long-haul motor carrier dispatchers as to determinants of drivers' schedules.

Sample Size: 309 long-haul drivers; 270 long-haul motor carrier dispatchers

Industry Sector: Long-haul motor carriers

Major Limitations: Dispatchers reported that shippers rarely requested tight delivery schedules. However, there is a possibility that dispatchers may have responded to questions about tight delivery schedules according to typical driver work schedules rather than HOS regulations. In particular, the authors note, that the study "did not attempt to quantify how a dispatcher defined 'more than enough time,' 'just enough time,' or 'not enough time' to pickup and deliver.

The drivers interviewed for this study were interviewed during summer morning hours at two specific sites. As a result, the authors note that "whether afternoon or nighttime truck traffic differs from morning traffic in terms of shippers' requested delivery schedules, whether these sites differ from others in the United States, and whether there are seasonal variations in motor carrier characteristics at these sites cannot be assessed from existing data."

Findings:

1. Approximately 20% of drivers reported penalties (e.g., fines, suspension, demotion, reprimands) from their motor carriers for late deliveries.

2. Motor carrier dispatchers pointed to multiple sources of information to determine the time required to make a particular trip: computer programs (75%), miles to be traversed (58%), speed limits (27%), and experience (13%).
3. Two-thirds of the dispatchers said they used rules of thumb for the average speed drivers could travel. Thirty percent said specific routes were examined.
4. "Among all dispatchers (i.e., both using and not using rules of thumb) 18% reported using 50 mph or slower; 14% used 51–55 mph; 21% used 55–60 mph; and 14% used a speed in excess of 60 mph."
5. "There was no association between the following variables and reports of expecting average speeds faster than 60 mph: penalties assigned for late delivery (reported by driver or dispatcher), hauling perishable products, and owner-operator status."
6. 61% of respondents said that time allotted per shipment for non-driving duties were up to the driver. Of those giving a quantitative estimate, most expected 2 to 4 hours.
7. Few dispatchers reported penalties imposed by shippers for late deliveries although 20% of drivers reported penalties from their motor carriers for late deliveries. Approximately 60% percent of dispatchers said this never happened and 40% said it rarely happened.
8. In response to questions regarding shipper time frames, more than one-third of dispatchers said 95% or more of their shippers gave more than enough time for deliverables to be made. Only 12% of dispatchers said that 10% or more of shippers give insufficient time for pick up and delivery. More than 80% of dispatchers said that zero shippers request insufficient time.
9. Of the 233 of 270 dispatchers who had the authority to accept or reject loads, only 9% mentioned the HOS status of the nearest driver as a factor in their decision.
10. The authors conclude, "according to dispatchers, revenue generation is a primary determinant in decisions to accept or reject loads. Delivery deadlines and the HOS status of the nearest driver were cited much less frequently. Revenue, probably, is a strong influence on delivery schedules in the very competitive trucking industry."

Findings Directly Related to HOS (include page references):

Driver Duration

p. 199, "*Dispatchers were asked about factors affecting their decisions to accept or reject loads (Table 5), and 233 of 270 said they had the authority to make such decisions. Among these 233 dispatchers, revenue was cited by 75%, followed by the credit rating of the shipper (41%), the need to find a back haul (load for return trip; 26%), the delivery deadline (24%), and whether the shipper was a regular customer (19%). The hours-of-service status of the nearest driver was mentioned by 9% of respondents."*

p. 201, *"Federal and state efforts to decrease violation-inducing delivery schedules appear more likely to succeed if they continue to be directed primarily toward motor carriers. If government agencies start to monitor driver adherence to work hour limits effectively, then motor carriers will have no choice but to refuse shippers' requests for unreasonable delivery schedules."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Campbell, K. "Estimates of the prevalence and risk of fatigue in fatal accidents involving medium and heavy trucks." 2002. University of Michigan Transportation Research Institute.

Abstract: This paper summarizes the results of a report on baseline estimates of the prevalence and risk of truck driver fatigue in fatal accidents that was prepared for the FMCSA in support of the HOS rulemaking. Data is presented on fatigue in fatal accidents by power unit type, trip distance, for-hire versus private carriers, time of day, and by hours driving. Fatigue was coded as a contributing factor for 511 truck drivers (1.9%) out of a total of 27,463 medium and heavy trucks involved in fatal accidents from 1991 to 1996. More than half of all fatigue-related fatal accidents involve for-hire tractors on trips of a one-way distance of more than 200 miles. "The risk of a fatigue-related fatal accident increases with trip distance." The fatigue risk "increases with hours driving in any operating environment and shows the characteristic circadian pattern."

Methodology: The report is based on data from the UMTRI Trucks Involved in Fatal Accidents (TIFA) files and the 1992 Truck Inventory and Use Survey (TIUS) conducted by the Bureau of the Census. The data is used to provide estimates of the vehicle miles of travel and fatal accidents involving fatigue for various segments of the trucking industry. In addition, the incidence of fatigue accidents is combined with travel data to estimate the overall risk of fatigue in fatal accidents. The authors use the same definition of fatigue as coded in the Fatality Analysis Reporting System (FARS).

Scope of Work: Report looks at TIFA and TIUS data from 1991 to 1996. Truck driver fatigue is the dependent variable and power unit type, trip distance, for-hire versus private carriers, time of day, and hours driving are the independent variables for the analysis.

Sample Size: Over 27,463 medium and heavy trucks involved in fatal accidents over the 6-year period

Industry Sector: Medium and heavy trucks

Major Limitations: The coding of fatigue is taken from the "driver-related factors" variables in FARS which relies on the original police accident report. The authors note that the coding of fatigue by state shows some large variations. In addition, the authors note that fatigue is "particularly difficult to assess, even with in-depth investigations, since there is no physical evidence of fatigue." The authors suggest that the "prevalence of fatigue reported here is in all likelihood too low."

Findings:

1. Fatigue is coded as a contributing factor for 511 truck drivers (1.9%) out of a total of 27,463 medium and heavy trucks involved in fatal accidents from 1991 to 1996.
2. The prevalence of truck driver fatigue in fatal accidents by time of day for all medium and heavy trucks involved in fatal accidents from 1981 to 1996 follows the circadian pattern.
3. (p. 23) ". . . more than half of all fatigue-related fatal accidents involve for-hire tractor on trips with a one-way distance of more than 200 miles. The risk of a fatigue-related fatal accident increases with trip distance. Straight trucks have a substantially higher risk of a fatigue-related fatal accident when operated on trips outside the local area, as compared with tractor combinations. For-hire carriers have a greater risk of fatigue-related fatal accident involvement based on miles traveled in nearly all operating environments as compared with private carriers. Finally, the fatigue risk increases with hours driving in any operating environment and shows the characteristic circadian pattern."
4. The prevalence of truck driver fatigue was shown for six industry groups: Straight: Local, 50 to 200 miles, >200 miles; Tractor: Local, 50 to 200 miles, >200 miles. The

greatest portion (62.3%) of the fatigue cases was in the category for tractors on trips greater than 200 miles.

5. The majority of reported fatigue occurs in the first few hours of driving as "half of all reported truck driver fatigue occurs in the first four hours of driving" for trucks involved in fatal accidents from 1981 to 1996. More than 25% of the accidents occurred in the first hour, and two-thirds in the first 4 hours. "Only about 4 percent of all medium and heavy truck drivers involved in a fatal accident reported driving more than 8 hours at the time of the accident." The authors note that this pattern is driven "by exposure, not risk" as the "nature of the exposure distribution will always keep the number of accidents after many hours driving a small proportion of the total, even with dramatic increases in risk with hour driving." (In other words, there are more 4-hour trips than 8-hour or 12-hour trips). Consequently there will be more accidents associated with 4-hour trips than with 12-hour trips. This is a different issue from the risk per 4-hour trip or per 12-hour trip—the per trip risk is higher for longer trips.) The authors also note that fatigue is cumulative and that while the amount of work and rest during the previous day and week also affect the level of fatigue during any hours of the current trip, no information on the previous work schedule was available for this study.
6. The relative *risk* of fatigue given involvement in a fatal accident follows the circadian rhythm.
7. The relative *risk* of fatigue given involvement in a fatal accident gradually increases during the first 8 hours, doubles during the ninth hour and is higher by a factor of 6 by the 12th hour.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 3, *"The reporting of fatigue was also examined for collisions where the only fatalities were truck occupants. Overall, 14% of all trucks involved in fatal accidents had one or more fatalities in the truck. Of the truck occupant fatalities, 9.5 percent (361 cases) were coded for truck driver fatigue. These fatigue cases are 70 percent of all fatigue coded for truck drivers in the TIFA data for 1991–1996. The proportion of fatigue in the non-truck fatalities is 0.6 percent."*

p. 23, *"Risk increases steeply after eight hours of driving. However, most of the fatigue-related fatal accidents occur during the first four hours of driving. This result may suggest that cumulative fatigue is a greater problem than hours driving on any given day, although exposure data are needed to confirm the result. The circadian pattern has a pervasive effect on both the risk and the prevalence of fatigue-related fatal accidents. The risk of a fatigue-related fatal accident is elevated by a factor of four in the early morning hours. Only driving more than 10 hours produces comparable risk levels. Time of day and hours driving are the dominant risk factors. Distributions of these factors suggest that the lower risk of fatigue-related fatal accidents of private carriers operating long-haul tractors may be due to less nighttime driving and shorter driving hours."*

Driver Duration

p. 17, "*The relative risk of fatigue gradually increases during the first 8 hours. During the ninth hour the fatigue risk is nearly double and by the 12th hour the risk is higher by a factor of over 6. A pronounced increase is also shown in the fifth hour. Fatigue risk drops back below 1.0 during the sixth hour and increases with each additional hour. Aggregate risk for the second four hours is greater than the first four hours by a factor of 1.6. This pattern holds in every subset examined… While these results confirm the generally accepted fact that fatigue increases with time on duty, they also illustrate that time on duty is not the only factor. The time of day when each hour of driving takes place also influences the risk of* *fatigue. It is likely that there is a strong interaction between time of day and hours of driving. The risk of fatigue when the eighth hour is driven at 4 a.m. is likely to be much higher than when the eighth hour is driven at 5 p.m."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Folkard, S. and Lombardi, D.A., “Designing Safer Shift Systems.” (2004). In P. Nickel, K. Hanecke, M. Schutte and H. Grzech-Sukalo, (Eds.) Aspekte der Arbeitspsychologies aus Wissenschaft und Praxis. pp. 151–166. Lengerich: Pabst Science Publishers.

Abstract: This article reviews the literature on shiftwork safety and the “related evidence on sleep duration, fatigue, and performance capabilities.” It focuses on studies in which “real measures of injuries and/or accidents can be related both to the time of day and/or to the point within the shift system that they occurred.” The studies look at specific features of shifts such as type of shift, length of shift, and number of successive shifts. The authors found a highly significant main effect of shift (i.e., risk increased on afternoon and night shifts relative to the morning shift) and a consistent trend in accident risk over four successive nights (i.e., risk was progressively higher on 2nd, 3rd and 4th nights than first night). The authors also discuss measures of fatigue and performance capabilities and how “relative risk estimates might be combined or pooled in a simple manner to provide an overall estimate of the relative risk over any given span of shifts, and hence for an entire shift system.” This estimate would allow for a “comparison of the estimated risk on different shift systems and further facilitate the design of safer shift systems.”

Methodology: The authors used two forms of analyses to examine the trends discussed in the article. A repeated-measures analysis of variance based on the relative risk values calculated for each data set was used as well as a chi-square analysis based on the summed frequency of incidents, giving equal weight to injuries and accidents. Both forms of analyses were used to overcome the shortcomings associated with each form by itself. The authors note specific aspects of the data that were problematic. For example, they had to correct the data in some studies to take account of inequalities in the number of workers. In addition, while some studies “give no precise details of the shift system in use, many of them involved a total of only four days on each shift before a span of rest days.” The authors also discuss the various problems associated with the priori risk of accidents and injuries. Few published studies allow for an unbiased calculation of relative risk estimates of accidents and/or injuries associated with specific features of shift systems due to non-homogeneous a priori risk (e.g., number of individuals at work is not constant over 24-hour day; number of supervisors, etc.).

Scope of Work: Literature review of shiftwork safety and estimates of relative risk over a span of shifts.

Sample Size: The number of articles reviewed was not stated.

Industry Sector: Shiftwork systems

Major Limitations: The authors note that there are “few published studies that allow for an unbiased calculation of relative risk estimates of accidents and/or injuries associated with specific features of shift systems due to non-homogeneous a priori risk.” As a result, their analyses are often based on one or two studies. They also note that “three of the studies report two separate sets of data, for different areas or types of incident, giving a total of eight data sets across the three shifts. Further, while some of the studies give no precise details of the shift system in use, many of them involved a total of only four days on each shift before a span of rest days.”

Findings:

1. Both analyses yielded a highly significant main effect of shift. Based on pooled frequencies, risk increased on the afternoon and the night shift relative to the morning shift.
2. There is a consistent trend in accident risk over 4 successive night shifts. However, the authors are unsure what happens to risk over longer successive night shifts, as there is a paucity of data relating to this. Only two studies reported incidence rates for a span of more than 4 night shifts and both of these studies were based on a relatively small number of incidents. However, it is noteworthy that both studies reported a decrease in risk from the fourth to the fifth night shift, which was maintained until the seventh and final night shift in one of the studies.

3. The authors questioned whether the increase in risk over successive shifts is confined to the night shift, or whether it might be general to all shifts and represent an accumulation of fatigue over successive workdays. While there was no evidence of a main effect of successive shifts using the repeated measures analysis of variance, the chi-square test yielded a significant effect of successive shifts, however it was substantially smaller than that over successive night shifts. On average, risk was about 2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift.
4. Three studies that reported the trend in risk over successive hours on shift and were corrected for exposure in some way were used for an analysis of the main effect of time on shift. Risk increased in an approximately exponential fashion with time on shift. The repeated-measures analyses of variance yielded a highly significant main effect of time on shift. A chi-square test was not possible as each study had to correct for exposure in some way and thus combining raw frequency scores would be biased.
5. The authors estimated the relative risk of shifts of different lengths by "differentiating the trend shown in Figure 4" (i.e., the mean relative risk over hours of duty found in 3 studies) and this result is shown in Figure 5." From Figure 5, "it is clear that variations

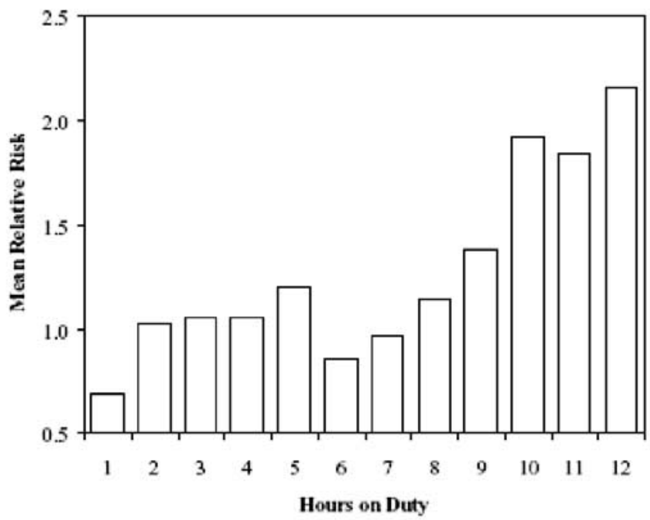

Figure 4. The mean relative risk over hours on duty.

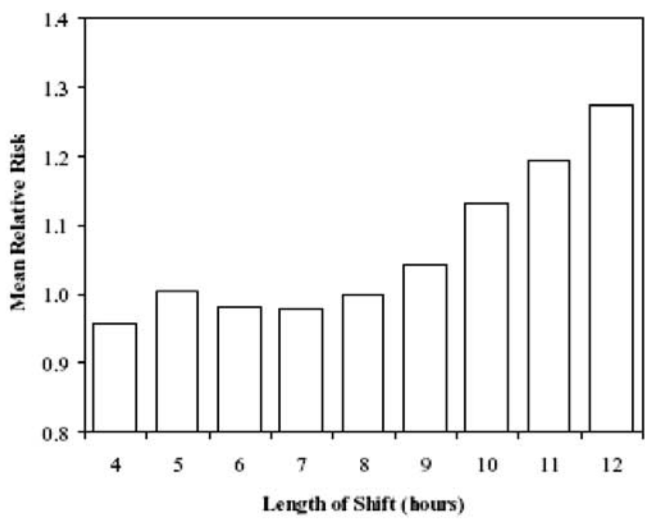

Figure 5. The estimated relative risk on different lengths of shift.

in shift length from about 4 to 9 hours will have relatively little impact on overall safety." They note, however, that the most important point is that they can "estimate the change in risk associated with shorter or longer shifts. They can estimate that relative to "8 hour shifts, 10 hour shifts are associated with a 13.0% increased risk and 12 hour shifts with a 27.5% increased risk."

6. The authors note that this trend for hours on duty did not control for the influence of breaks during a duty period. Only one recent study examined the impact of rest breaks on the risk of incidents. Injuries in an engineering plan in which 15-minute breaks were given after each period of 2 hours of continuous work were calculated. "The risk in each 30-minute period was expressed relative to that in the first 30-minute period immediately following the break." The study found that risk rose substantially, and approximately linearly, between successive breaks such that risk had doubled by the last 30-minute period before the next break. There was no evidence that this trend differed for the day and night shifts, or for the three successive periods of two hours of continuous work within a shift."
7. The authors offer a model of how relative risk estimates might be combined or pooled in a simple manner to provide an overall estimate of the relative risk over any given span of shifts. The following figures show the estimated relative risks for different spans and lengths of day shifts (Figure 1) and night shifts (Figure 2):

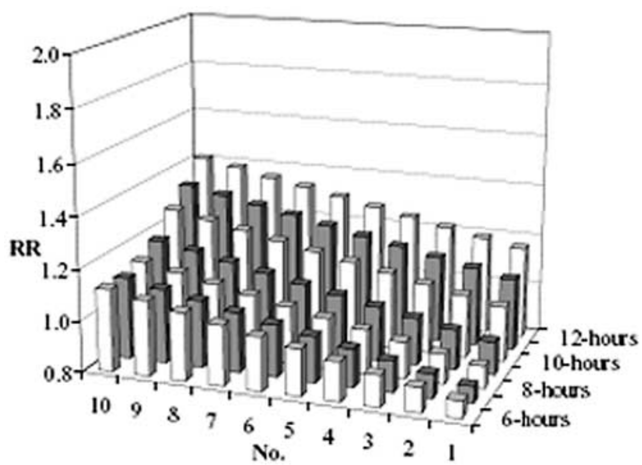

Figure 1. Estimated relative risks for different spans and lengths of Day shifts.

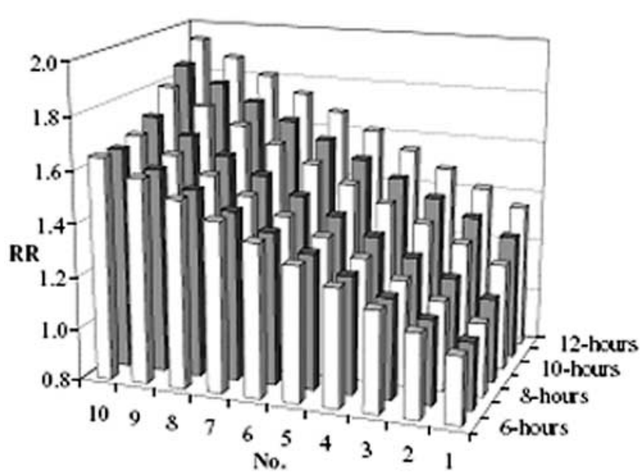

Figure 2. Estimated relative risks for different spans and lengths of Night shifts.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 5, *"Based on these pooled frequencies, risk increased in an approximately linear fashion, with an increased risk of 18.3% on the afternoon shift, and of 30.4% on the night shift, relative to the morning shift…This finding suggests that when the a priori risk appears to be homogeneous across the three shifts, there is a consistent tendency for the relative risk of incidents to be higher on the afternoon shift than on the morning shift, and for it to be highest on the night shift."*

p. 6, *"There is also a consistent trend in accident risk over successive night shifts . . . On average, risk was about 6% higher on the second night, 17% higher on the third night, and 36% higher on the fourth night."*

p. 7, *"On average, risk was about 2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift."*

p. 8, *"Thus while it remains a possibility that over longer spans of night shifts risk may actually start to decrease after the fourth night, there is no current evidence to indicate that this is actually the case."*

p. 10, *"A repeated measure analysis of variance of the relative risk values for the five data sets indicated that there was no evidence of a main effect of successive shifts. However, this may reflect the relatively small number of incidents and limitations of some of these studies . . . A chi-square test based on the summed frequencies across the five studies for the four successive shifts yielded a significant effect of successive shifts. These summed values were used to estimate the risk on the successive morning/day shifts relative to the first such shift . . . On average, risk was about 2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift . . . Clearly there is some evidence. albeit relatively inconsistent compared to the other trends reported in this chapter, that risk increased over successive morning/day shifts. However, it is important to note that this increase was substantially smaller than that over successive night shifts. Thus, there is evidence for an increase in risk over successive workdays, irrespective of the type of shift, but also evidence that this increase is substantially larger on the night shift than on the morning/day shift."*

p.10, *". . . apart from a slightly heightened risk from the second to fifth hour, risk increased in an approximately exponential fashion with time on shift."*

p.10, *". . . we can estimate that relative to eight hour shifts, ten hour shifts are associated with a 13/0% increased risk and twelve hour shifts with a 27.5% increased risk."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Frith, W.J. "A case control study of heavy vehicle drivers' working time and safety." (1994.) Proceedings 17th ARRB Conference, Part 5:17–30. Queensland, Australia.

Abstract: This article describes a study on the risk of crash with respect to driving hours and other time intervals related to the driver's working lives. A 'case' group of heavy vehicles involved in crashes were compared to a 'control' group of vehicles. The crash-involved drivers were 2.6 times more likely, as compared with non-crash involved drivers, to have driven 8 or more hours since the last compulsory 10-hour off-duty period (as recorded in the log book). They found no other "significant differences between the two groups with respect to other time intervals related to driving habits." However, there was a "significant difference between the age distribution of the crash and control drivers with the crash drivers generally younger."

Methodology: A 'case' group of heavy vehicles involved in crashes was compared with a 'control' group of vehicles. The 'control' group of vehicles was selected by police going to the scenes of crashes on as close as possible to the exact anniversary of the crash, at the same time of day and stopping the first heavy vehicle of a similar configuration to the crash involved vehicle. When possible, police selected vehicles traveling in the same direction. If, after an hour of waiting, no suitable vehicle came, they selected a vehicle of a different configuration. Matching "by configuration was possible in 143 out of 199 useable pairs." Details of drivers' hours for the 'case' vehicles were known from their log books. The police collected driving hour details from the 'control' vehicle drivers along with other vehicle and driver details. The study was carried out in New Zealand in urban and rural areas between June 1992 and July 1993. The crash dates ranged from 1988 through 1990.

Scope of Work: Comparison of heavy vehicle crashes with a control group

Sample Size: 199 pairs of crash and control vehicles

Industry Sector: New Zealand heavy vehicles

Major Limitations: There is a lag of 2 years between the beginning of the survey of control drivers and the last of the crashes. However, the authors did not believe that there was any significant change in driving habits or the driving environment between the period during which the crashes occurred and the period over which the control survey took place.

The authors note that as with other studies using log book data, the drivers' log book system in New Zealand is open to falsification. As there were very few observations in which hours restrictions were violated, the authors suspect that falsification may have occurred and that the "probable effect of this in the data would be to shift, in both groups, some data which should rightly appear in illegal cells, into marginally legal cells." They believe this effect "may be greater in the crash sample than the control sample."

Findings:

1. The crash-involved drivers were 2.6 times more likely, as compared with non-crash involved drivers, to have driven 8 or more hours since the last compulsory 10-hour off-duty period (as recorded in the log book).
2. Crash involvement tends to increase more steeply for smaller rigs than larger rigs. The authors note that this might reflect greater use of smaller rigs by tired drivers in congested environments.
3. The lengths of the following time periods related to drivers' work were *not* found to be statistically significant related to crash risk:
   i. The total elapsed time since the driver's last 24-hour off-duty period
   ii. On-duty hours worked since the driver's last 24-hour off-duty time

   iii. Driving hours worked since the driver's last 24-hour off-duty time
   iv. On-duty hours worked 'today' since the driver's last 10-hour off-duty time
4. However, the authors note "indications of a rough progression towards statistical significance as the work-related periods measured became more immediately related to the final driving period." They note "significant changes in time in some of the above measurements may have been detected had a larger scale study been possible."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 28 , *"Crash involvement increases significantly after about 8 hours worked from the last 10 hour rest period."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Harris, W. "Fatigue, circadian rhythm, and truck accidents." Theory, Operational Performance, and Physiology Correlates (ed. Mackie, R.) (1978). 133–46. NY, NY: Plenum Press.

Abstract: Truck accident data were analyzed to see if fatigue and circadian rhythm effects were present in truck accidents that seemed to be the result of failures in vigilance performance. Data was analyzed for three groups of drivers: dozing drivers, those who had had single-vehicle accidents, and those who had crashed into the rear end of other vehicles. The effect of fatigue was confirmed for each of the groups. The "circadian effect was observed for dozing drivers, about twice as many of whose accidents occurred between midnight and 0800 than in the other 16 hours of the day, and for single-vehicle accident drivers, about half of whose accidents occurred in the early morning hours."

Methodology: Bureau of Motor Carrier Safety accident report data was analyzed. Data was analyzed for three groups of drivers: dozing drivers, those who had had single-vehicle accidents, and those who had crashed into the rear end of other vehicles. Different types of exposure data (e.g., expected durations of trips on which accidents occurred) were taken into account.

Scope of Work: Truck accident data analysis

Sample Size: Bureau of Motor Carrier Safety accident data—various sample sizes

Industry Sector: Truck drivers

Major Limitations: n/a

Findings:

1. The 1974 accident report data for 406 dozing truck drivers was analyzed. "Nearly twice as many accidents occurred in the second half of trips (65%) than in the first half (35%). The median trip duration was 7.5 hours; the median driving time for an accident was 4.4 hours. The fatigue hypothesis was supported by the data."
2. The accident report data for 493 dozing truck drivers was analyzed. Analysis showed that the circadian effect was evident as the highest percentage of accidents occurred between 0400 and 0600 which corresponds to the occurrence of the lowest mean deviation in heart rate. In addition, "twice as many accidents occurred between midnight and 0800 (66%) than in the other 16 hours of the day (34%). Note: This effect is even more pronounced if exposure data (i.e., the relative number of trucks on the highway by time of day) are taken into account.
3. Single-vehicle accidents strongly showed the circadian effect as approximately 70% of the accidents occurred between midnight and 0800. In contrast, only 34% of other-vehicle accidents occurred in the early morning hours.
4. Two samples of randomly selected truck accident data from 1976 were analyzed: 226 single-vehicle accidents and 116 accidents where the truck crashed into the rear of another vehicle. The samples were selected irrespective of the driver's condition at the time of the accident. The circadian effect was evident for the single-vehicle accident sample as 46% of the accidents occurred between midnight and 0800, almost "2.5 times as many as would be expected from the exposure data (19%). Approximately 70% of those drivers who checked "dozed at the wheel" occurred between midnight and 0800." In contrast, only approximately 25% of the accidents for the other-vehicle accident sample occurred between midnight and 0800. For the two samples of data, the "crossover" from "less than expected" to "more than expected" percentage of accidents occurred between the "fifth and sixth hours of driving time." Approximately, "twice as many accidents occurred in the second half of the trips (67%) as in the first half (33%, irrespective of trip duration)."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 144, *"The fatigue hypothesis was supported by the results of the analyses of the accident report for each of the groups studied: dozing-driver, single-vehicle, and other-vehicle accidents."*

p. 145, *"The circadian effect was observed for both dozing drivers and the single-vehicle accident drivers."*

Driver Duration

p. 145, *"The fatigue and circadian effects observed in the analyses of the accident data raise a question about the possible combined effects of long hours on the road and time of day. What is the relative likelihood of an accident for a driver who finds himself still on the road at 0400 or 0500 in the morning after, say, 8 hours of driving? There is some evidence that there is a combined effect from the heart rate data for relay drivers observed in the earlier study (Harris & Mackie 1972)… The evidence suggests that trips should not be scheduled so that drivers will still be on the road, after many hours of driving, at times of the day when their capabilities to attend to the driving task are at a low ebb."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Hartley, L. "Australian initiatives in managing fatigue in transportation." Insurance Commission of Western Australia. (1999)(www.officeofroadsafety.wa.gov.au/Facts.papers/initiatives_in_managing_fatigue.html).

Abstract: This paper contains a description of two Australian alternatives to the traditional hours of service regime. In addition, the paper contains a comparison of various studies on the impact of fatigue on heavy vehicle drivers.

Methodology: The authors compare Hartley et al.'s (1996) study on the impact of fatigue on heavy vehicle drivers in Western Australia (WA) (where there are no HOS regulations), with Williamson and Feyer's 1992 study, which contained a comparable survey of drivers working under HOS in the Eastern States. For their study, Hartley and his colleagues interviewed 638 drivers and 83 transport companies at various locations in the state. A few years prior to this study, Williamson and Feyer conducted their survey in the Eastern States.

Scope of Work: Meta-analysis

Sample Size: n/a

Industry Sector: Truck driving

Major Limitations: In comparing Williamson et al. and Hartley et al.'s data on drivers' perception of fatigue, it should be noted that both studies asked rather different questions. The WA study used "one scale running through 'always a problem' to 'never a problem.' Williamson used two scales running through 'every trip' to 'very rarely' or 'major problem' to 'no problem.'

Findings: *Does HOS restrict fatigue?*

1. The percentage of drivers exceeding 72 hours work in Williamson et al.'s survey is slightly in excess of the WA survey, which found 30% exceeded 72 hours work.
2. "To the extent to which the present WA data and Williamson et al.'s data are comparable, fewer WA drivers (4.4%) consider fatigue to be always a problem than do their Eastern States' counterparts consider it to be a major problem or occurring on every trip (8.6 and 10.7%). And rather more WA drivers consider it to be never a problem (35%) as compared with Eastern States drivers (15%) who very rarely feel fatigued or consider it is no problem."
3. According to the results of a comparison of the self-report data from Williamson et al. (1992) and Hartley et al. (1996), fatigue appears to be regarded as a more significant problem for the industry among Williamson's Eastern States drivers than it does in the WA sample.
4. The authors list the following problems with HOS:
   - HOS prescribe what a driver should be capable of doing (i.e., no flexibility).
   - HOS regulations do not inform organizations about fatigue and safety.
   - HOS regulations permit no discretion for different freight tasks and environments.
   - HOS do not take account of the influence of the driver's circadian cycle.
   - HOS regulations take no account of time zone changes.
   - HOS may restrict access to sleep.
   - There is no commercial incentive to restrict driving to HOS.

Findings Directly Related to HOS (include page references):

Driver Duration

p. 3, *"It appears that WA drivers are no more likely to exceed weekly driving hours regulations than their Eastern States' counterparts, despite enforcement of driving hours regulations in the Eastern States."*

p. 3, *"To the extent to which the present WA data and Williamson et al.'s data are comparable, fewer WA drivers (4.4%) consider fatigue to be always a problem than do their Eastern States' counterparts consider it to be a major problem or occurring on every trip (8.6 and 10.7%). And rather more WA drivers consider it to be never a problem (35%) as compared with Eastern States drivers (15%) who very rarely feel fatigued or consider it is no problem."*

p. 3, *"The Eastern States drivers were more likely to report that long driving hours and poor sleep were fatiguing than WA drivers, despite regulation of driving hours in the Eastern States."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Hertz, R. P. "Hours of service violations among tractor-trailer drivers." (1990). *Accident Analysis & Prevention*, Vol. 23, No. 1, 29–36.

Abstract: This study examines estimated HOS violations of more than 1-hour among long-distance truck drivers based on observed departure and arrival at inspection stations. Service violations were estimated by observing the same long-haul tractor-trailers leaving "one inspection station (Point A) and entering another (Point B), estimating their travel speed excluding required rest, and estimating hours of rest taken on the basis of the observed travel time and the estimated speed." The drivers used for the estimation were interviewed at the first inspection station and observed thereafter. Only truckers driving alone who reportedly did not plan to make an interim delivery or pickup stop prior to arrival at the second inspection station were included in the calculation. At "assumed trip speeds of 40 mph and 50 mph, 90% and 51% of the drivers, respectively, were in violation of the hours of service rules by more than one hour."

Methodology: The authors estimated violations of the HOS regulations by comparing observed trip time between Washington and Minnesota "with the minimum legal amount of time it would have required to make the trip if the driver took all required rest." The minimum legal trip time was calculated as the "sum of the driving hours between Washington and Minnesota (including time for stops other than required rest) plus the hours of required rest." As the authors did not know actual driving hours and hours of rest they arrived at a range of estimates for the driving hours between Washington and Minnesota by assuming that the actual trip speed (excluding required rest but including other necessary stops) lay somewhere between 35 mph and 65 mph. The authors also made estimates of required hours of rest for each estimate of driving hours based on federal regulations allowing 10 hours of driving after 8 hours of off-duty time. To compute the hours of required rest, the number of driving hours the driver reported prior to Spokane was added to the driving hours estimated between Spokane and Minnesota. The authors added the corresponding estimates of driving time between Spokane and Minnesota to the required hours of rest to obtain the minimum legal trip time. Violations were assumed if the sum was more than 1 hour greater than the observed travel hours between the Spokane departure and the Minnesota arrival.

Scope of Work: Estimated HOS violations based on interviews and observations.

Sample Size: 130 long-haul tractor-trailer drivers, driving alone

Industry Sector: Long-haul tractor-trailer

Major Limitations: The authors note that a "precise estimate of hours of service violations cannot be calculated without knowing the actual speed distribution of the drivers in the sample."

Findings:

1. 90% of the drivers were in violation of the HOS rules by more than 1 hour by the time they arrived at the Minnesota observation site with an assumed average trip speed of 40 mph.
2. 51% of the drivers were in violation of the HOS rules by more than 1 hour with an assumed average trip speed of 50 mph.
3. 24 hours rest was required by 81% of the drivers at an assumed speed of 40 mph compared with 18% of the drivers at an assumed speed of 50 mph.

Findings Directly Related to HOS (include page references):

Driver Rest

p. 34, *"At an assumed trip speed of 40 mph, 16 hours of rest was required by 17% of the drivers, 24 hours of rest was required by 81% of the drivers, and 32 hours of rest was required by 2% of the drivers."*

p. 34, *"At an assumed trip speed of 50 mph, 16 hours of rest was required by 82% of the drivers and 24 hours of rest was required by 18% of the drivers."*

p. 34, *"At an assumed trip speed of 40 mph, 36% of the drivers missed more than 70% of required rest, 61% missed more than 50% of the rest, and 88% missed more than 10% of the rest."*

p. 34, *"At an assumed trip speed of 50 mph, 9% of the drivers missed more than 70% of the required rest, 20% missed more than 50% of the rest, and 48% missed more than 10% of the rest."*

p. 34, *"At 40 mph, 42% of the drivers missed more than 15 hours of required rest, 81% of the drivers missed more than 5 hours of rest, and 90% of the drivers missed more than 1 hour of rest.*

p. 34, *"At 50 mph, 7% of the drivers missed more than 15 hours of required rest, 36% of the drivers missed more than 5 hours of rest, and 51% of the drivers missed more than 1 hour of rest."*

Driver Duration

p. 33, *"At an assumed average trip speed of 40 mph, 90% of the drivers were in violation of the hours of service rules by more than one hour by the time they arrived at the Minnesota observation site. With an average trip speed of 50 mph, 51% of the drivers were in violation by more than one hour."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Jones, I.S. and Stein, H.S. "Effect of driver hours-of-service on tractor-trailer crash involvement." (1987). Arlington, VA. *Insurance Institute for Highway Safety.*

Abstract: In 1987, the Insurance Institute for Highway Safety in the United States used a case-control approach to examine the relative risk associated with long hours of driving (Jones and Stein 1987). For each large truck involved in a crash, three trucks were randomly selected from the traffic stream at the same time and place as the crash but 1 week later. A sample of 332 tractor-trailer crashes, each with one, two, or three case controls was extracted for analysis. For tractor-trailers, the authors found that driving in excess of 8 hours, drivers who violate log book regulations, drivers aged 30 and under, and interstate carrier operations were associated with an increased risk of crash involvement. In particular, the relative risk of crash involvement for drivers who reported a driving time in excess of 8 hours was almost twice that for drivers who had driven fewer hours.

Methodology: A case-control method of analysis was used whereby three trucks were selected and inspected for each crash-involved truck. The trucks were selected and inspected at the crash site at the same time of the day as the crash but 1 week later. In addition to information on truck weight, size, configuration, and type of carrier, data were collected on driver age and experience, hours of driving, and log book violations. Hours of driving was recorded as "the number of hours driven since the last eight hour rest period," using a variety of sources (e.g., driver's statement, log book record, bill of lading, current vehicle location, etc.). The study included 676 crashes involving 734 large trucks that occurred between June 1984 and July 1986. The analysis was limited to crashes involving tractor-trailers and their controls. The final subset represents 332 matched case-control data sets.

Scope of Work: Investigation of large truck crashes on interstate highways in Washington State.

Sample Size: The study included 676 crashes involving 734 large trucks that occurred between June 1984 and July 1986. The analysis was limited to crashes involving tractor-trailers and their controls. The final subset represents 332 matched case-control data sets.

Industry Sector: Large trucks

Major Limitations: n/a

Findings:

1. For tractor-trailers, the authors found that driving in excess of 8 hours, drivers who violate log book regulations, drivers aged 30 and under, and interstate carrier operations were associated with an increased risk of crash involvement.
2. The relative risk of crash involvement for drivers who reported a driving time in excess of 8 hours was almost twice that for drivers who had driven fewer hours.
3. The risk from driving long hours increases for drivers operating between 12:01 a.m. and 6:00 a.m. and 6:01 a.m. and noon.

Findings Directly Related to HOS (include page references):

Driver Fatigue

p. 15, *"What is important from this study is that the relative risk of crash involvement for drivers driving more than eight hours is almost twice that for drivers with fewer hours behind the wheel… the risk from driving long hours increases for drivers operating between 12:01 a.m. and 6:00 a.m. and 6:01 a.m. and noon."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Alison Smiley, Dianne Davis

Title: Jovanis, P.P. and Kaneko, T. "Exploratory analysis of motor carrier accident risk and daily driving patterns." (1990). Transportation Research Group, University of California at Davis. Research Report UCD-TRG-RR-90-10, 1990.

Abstract: The Jovanis and Kaneko (1990) report deals with the issue of cumulative days or hours of driving and crash rates. They report on an analysis of carrier-supplied accident and non-accident data for a 6-month period in 1984. The data were obtained from a "pony express" type operation, which operates coast to coast with no sleeper berths. Cluster analysis was used to identify nine distinct patterns of driving hours over a 7-day period. The driving patterns of drivers who had an accident on the 8th day were compared with drivers who had no accident on the 8th day. These patterns reflected times of day of most frequent onduty and driving time, the most frequent offduty times, the mean and standard deviation of the total hours onduty for the 7 days, the mean and standard deviation of consecutive hours driven per driver and the mean and standard deviation of the driving cycle. Their study indicates an increased accident risk for night drivers after 3 to 4 days of driving but less concern for daytime drivers with respect to a crash immediately following a 3- to 4-day period of driving.

Methodology: The data were obtained from a "pony express" type operation, which operates coast to coast with no sleeper berths. Cluster analysis was used to identify nine distinct patterns of driving hours over a 7-day period. The driving patterns of drivers who had an accident on the 8th day were compared with drivers who had no accident on the 8th day. These patterns reflected times of day of most frequent onduty and driving time, the most frequent offduty times, the mean and standard deviation of the total hours onduty for the 7 days, the mean and standard deviation of consecutive hours driven per driver and the mean and standard deviation of the driving cycle.

Scope of Work: An analysis of carrier-supplied accident and nonaccident data and driving patterns.

Sample Size: Approximately 1,600 accident- and nonaccident-involved drivers

Industry Sector: Less-than-truckload firm with no sleeper berths

Major Limitations: The authors did not include statistics on offduty times in excess of 24 hours. They assumed that a substantial recovery occurs when a driver is offduty in excess of 24 hours, after reaching the DOT limit of 60 hours in 7 days.

Findings:

1. Analysis showed that there was an increased accident risk for night drivers after 3 to 4 days of driving but less concern for daytime drivers with respect to a crash immediately following a 3- to 4-day period of driving.
2. Accident risk on the eighth day is shown to be consistently higher for the four patterns involving infrequent driving the first 3 to 4 days followed by regular driving during the last 3 to 4 days, than the 4 patterns with the reverse arrangement. This suggests cumulative fatigue from driving over 3 to 4 days does occur and leads to increased accident risk.
3. When the patterns are examined in detail, it appears that drivers who begin their trips near midnight and typically end them around 10:00 a.m. face a particularly increased crash risk after driving for several consecutive days. In contrast, drivers who typically drive a regular daytime schedule (10 a.m. to 6 p.m.) show little evidence of any effect due to continuous driving.
4. Total hours of driving in a 7-day period varied between averages of 54 to 59 hours among the nine patterns identified.

Findings Directly Related to HOS (include page references): Summary only available—no direct quotes.

Reviewers: Dianne Davis, Alison Smiley

Title: Kecklund, G., Akerstedt, T., Ingre, M., Soderstrom, M. "Train drivers' working conditions and their impact on safety, stress and sleepiness: a literature review, analyses of accidents and schedules." (1999). National Institute for Psychosocial Factors and Health (IPM). Department of Public Health Sciences, Division of Psychosocial Factors, Karolinska Institute, Stockholm, Sweden.

Abstract: This paper focuses on how train drivers' work hours and work situations influence safety and performance, "in particular in traffic intense areas, such as commuting." It contains a summary of the results of a literature review, an accident analysis, and an analysis of the timetable for train drivers located in the Stockholm area. The accident analysis examines 79 rail accidents, finding that approximately 17% were potentially related to fatigue or sleepiness.

Methodology: The authors conducted an analysis of investigations of 79 accidents and near-accidents occurring between 1980 and 1997 on the railway in Sweden. The investigations largely focused on the train driver's role in the events leading up to the accident. The goal of the analysis was to examine the extent to which working conditions could have contributed to the accidents/near-accidents. While most investigations did not contain information on whether stress or fatigue was involved at the time of the accident, they did contain information about when the incident occurred as well as the type of incident. The authors used a combination of factors to determine if fatigue was present at the time of the accident.

Indicators of suspected fatigue were considered to be present when one of the following three criteria appeared in combination with the fourth criterion:

1. The driver admitted or the investigator observed fatigue.
2. Time of the accident (the incident occurred between 3:00 a.m. and 6:00 a.m.).
3. Lack of sleep (less than 5 hours sleep) or a shift being preceded by a brief period of off-duty time (less than 11 hours).
4. Accidents or incidents characterized by missed signals, lack of attention or loss of memory. It is known that this type of event is frequently triggered by fatigue.

Scope of Work: An analysis of accident and near-accident investigations.

Sample Size: 79 accident and near-accident investigations were analyzed

Industry Sector: Train drivers

Major Limitations: The authors note that their results must be interpreted with caution as the investigations they analyzed frequently contained relatively sparse information on the working conditions at the time of the incident. As a result, they were required to infer if fatigue or stress was present at the time of the accident (see Methodology) but admit that this involves methodological shortcomings as there is a risk of incorrect classification. In addition, the authors note that as the number of accidents is low, the results should be interpreted with caution.

Findings:

1. "Three (4%) of the accidents were fatigue related according to criterion no. 1. However, this figure rose to 13 (17%) if all criteria were applied."
2. "Five of the accidents where fatigue was suspected were due to a brief period of sleep after an extremely early morning shift, three were due to the driver being at the lowest level of the circadian rhythm, and two to a short rest period and in all likelihood a brief period of sleep."
3. "The occurrence of incidents is at its lowest in the evening (between 10 p.m. and midnight) and at night (between 2 a.m. and 6 a.m.). Twelve percent of the incidents occurred

at night, between midnight and 6 a.m. Rather more than half (54%) of them occurred during morning traffic (starting before 9 a.m.).

4. "Most incidents (62%) occurred during the dark winter months, defined here as October through March."
5. "Seventy-five percent of the accidents occurred during the first three working hours. However, it should be noted that the sample is very small and there is serious risk that chance has influenced the result. It is reasonable to suppose that very few shifts indeed are shorter than 3 or 4 hours, although we do know that relatively many shifts are shorter than 7 hours. If it had been possible to calculate the risk of an accident occurring (i.e., take into account the number of shifts that are at least 3, 4, 5, 6, etc., hours long), the peak after 2–3 hours would probably be considerably lower, while the risk of accidents after 6–7 hours would be higher."

Findings Directly Related to HOS (include page references):

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Lenne, M.G., Triggs, T.J., and Redman, J.R. (1997). "Interactive Effects of Sleep Deprivation, Time of Day, and Driving Experience on a Driving Task." Sleep, Vol. 2, No. 1, 38–44.

Abstract: This study looked at the effects of sleep deprivation, time of day, and driving experience on a driving task. Twenty-four subjects (12 experienced and 12 inexperienced drivers) drove a driving simulator for 20 minutes at 5 different times of the day on 2 testing days. One testing day took place after a normal night's sleep. The other testing day took place after 1 night of sleep deprivation (SD). Reaction time, lateral position and speed were all assessed. "The standard deviation of both lateral position and speed were significantly higher during SD. Performance steadily improved across the day between 0800 and 2000, and the absence of any sleep-by-time interactions suggests that the rhythm of driving performance across the day was similar after both normal sleep and SD. Inexperienced drivers had higher RTs than experienced drivers in both sleep-deprived and non-sleep deprived conditions."

Methodology: Twelve inexperienced drivers (driver's license less than 3 years) and twelve experienced drivers (i.e., drivers' license for between 6 and 13 years) were recruited to participate in the study. Subjects participated in 2 testing days in which they drove the simulator for 20 minutes at 0800, 1100, 1400, 1700, and 2000. The first testing day took place after a normal night's sleep. The second testing day took place after 1 night of SD. Subjects completed visual analog scales (i.e., measured subjective alertness, sleepiness, motivation) immediately prior to and after each session. The between-subject variables were sleep condition, time of day, and block number with each session. The within-subject variable was the level of driving experience.

Scope of Work: Simulator study of experienced and experienced drivers.

Sample Size: 24 subjects; 12 female and 12 male (18 to 32 years of age).

Industry Sector: n/a

Major Limitations: The authors note that it could be argued that the improvements in performance observed across the day may reflect practice effects. However, they noted that their previous work suggests that this is not the case. "When driving ability was measured across the day, with testing times counterbalanced, performance was significantly more impaired late at night and in the early morning hours, with a steady improvement across the waking day."

Findings:

1. "Inexperienced drivers had higher secondary RTs than more experienced drivers. There was also an interaction between driving experience and sleep condition. Analysis of simple main effects confirmed that inexperienced drivers had higher RTs than experienced drivers in both the control and SD conditions. However, the presence of the interaction suggests that inexperienced drivers were impaired to a greater extent in the SD condition."
2. "There were no effects of driving experience for any of the driving performance measures."
3. Sleep deprivation for up to 36 hours significantly reduced the ability of all drivers to maintain a steady position in the lane and a stable speed.
4. Performance varied significantly across the day.
5. The absence of any interactions between sleep condition and time of day suggest that the patterns of performance across the day were similar after 1 night of sleep and 1 night of SD.
6. The results of the subjective measures of alertness, sleepiness, and motivation were consistent with the performance data to a large extent.
7. Differences between inexperienced and experienced drivers were found with the secondary RT task.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 42, *"Sleep deprivation for up to 36 hours significantly reduced the ability of both inexperienced and experienced drivers to maintain a steady position in the lane and a stable speed. The ability to attend to additional stimuli, as measured by the secondary RT task, was also significantly reduced by SD, particularly for inexperienced drivers."*

p. 42, *"A major finding of this study was that performance varied significantly across the day. The absence of any interactions between sleep condition and time of day suggests that the patterns of performance across the day were similar after a night of sleep and a night of SD. During both control and SD conditions, the ability to maintain both a stable position on the road and a constant speed improved across the day, while secondary RT decreased. In particular, during SD, subjects performed better at 2000 hours (36 hours SD) than at 0800 hours (24 hours SD). Similar performance rhythms during SD were found for lexical decision, vigilance, logical reasoning, reaction time, and memory and search tasks.*

p. 43, *"Differences between inexperienced and experienced drivers were found with the secondary RT task."*

p. 43, *"Performance during SD is not a monotonic function of the length of deprivation. This study has shown that performance still improved across the normal waking day following a night without sleep. These findings are relevant to those who are placed in situations where driving after a period of SD is unavoidable, as in the transportation industry."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Lin, T., Jovanis, P.P., and Yang, C. (1994). "Time of day models of motor carrier accident risk." Transportation Research Record 1467.

Abstract: The objective of this paper was to develop a quantitative method to analyze the effect of time of day on accident risk. A time-dependent logistic regression model was formulated to assess the safety of motor carrier operations. The model "estimates the probability of having an accident at time interval, *t*, subject to surviving (i.e., not having an accident) until that time." The model was then tested with data from trucking company operations. Analysis showed that driving time had the strongest direct effect on accident risk.

Methodology: The model was used with data obtained from a national less-than truckload firm that operated coast-to-coast with no sleeper berths. The total number of observations used for modeling was 1,924 cases, of which 694 were accidents and 1,230 were non-accidents.

Scope of Work: Creation of time-dependent logistic regression models to assess the safety of motor carrier operations.

Sample Size: 1,924 cases (i.e., 694 accidents and 1,230 non-accidents) were used for modeling

Industry Sector: Less-than-truckload; no sleeper berths

Major Limitations: While "time-dependent covariates play a key role in accident analysis," the authors note that the "shortage of time-varying data makes it difficult for a researcher to consider further accident analysis and solutions." For example, high traffic volume could be one of the reasons for the highest accident risk occurring between 4:00 and 6:00 p.m. The inclusion of time-varying risk factors, such as road class "could greatly improve understanding of time-related effects."

The authors also note that the "joint study of time of day and driving time is complicated because driving time intervals could cross more than one time of day. Although some rules have been provided in this research, the approach is still rough and could result in some loss of information and bias in estimation. A more advanced approach is needed to treat the coding of time of day precisely and completely.

Findings:

1. "Driving time has the strongest direct effect on accident risk."
2. "The first 4 hr consistently have the lowest accident risk and are indistinguishable from each other."
3. "Accident risk increases significantly after the 4 hr, by approximately 50 percent or more, until the 7th hr. The 8th and 9th hr show a further increase, approximately 80 and 130 percent higher than the first 4 hr."
4. "Drivers with more than 10 years of driving experience retain consistently low accident risk; all other categories of driving experience have a significantly higher risk."
5. "Daytime driving, particularly at the noon time (10:00 a.m. to 12:00 noon), results in a significantly lower risk of an accident." This was defined as the baseline.
6. The accident risk of driving during 4:00 to 6:00 p.m. is significantly higher (approximately 60% higher) than that of the baseline." This may result from a combination of two effects: evening rush hour and an association with reduced alertness because of a low circadian period for some drivers.
7. "The accident risks from midnight to 2:00 a.m., 6:00 to 8:00 a.m., and 8:00 to 10:00 p.m. are also significantly higher than during the baseline (but at $P < .10$). Two of these periods involve night driving; the other involves part of the dawn period."
8. Rest breaks, particularly those taken before the 6th or 7th hr of driving, appear to lower accident risk significantly for many times of day.

Findings Directly Related to HOS (include page references):

Driver Duration/Crash Risk

p. 7, *"Driving time has the strongest direct effect on accident risk. The first 4 hr consistently have the lowest accident risk and are indistinguishable from each other. Accident risk increases significantly after the 4th hr, by approximately 50 percent or more, until the 7th hr. The 8th and 9th hr show a further increase, approximately 80 and 130 percent higher than the first 4 hr."*

p. 7, *"Time of day had an effect on subsequent accident risk, but the effect was not as strong as for driving experience or driving hours. Daytime driving, particularly at noon (10:00 a.m. to 12:00 p.m.), results in a significantly lower risk of an accident. Driving from 4:00 to 6:00 pm. has an accident risk about 60 percent higher than the baseline; drivers during the other three significant times of day also have accident risks about 40 percent higher than those during the baseline. These three involve night or dawn driving; two of them are associated with circadian rhythms."*

p. 7, *"When interactions were included, the accident risk for some times of day decrease. Particularly, most of the significant interactions fall in the sixth and seventh driving hours. Rest breaks appear to be associated generally with these risk reductions."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Moore-Ede, M. and Schlesinger, B.I. "Scientific basis for challenges to work-rest & hours-of-service regs." (2005). Submitted to 2005 Fatigue Management in Transportation Operations International Conference, FMCSA and Transport Canada, Seattle, WA.

Abstract: The authors argue that scientific knowledge that has accumulated in the past 30 years "undermines the legitimacy of the 20th-century paradigm of hours-of-service and duty-rest regulation." They argue that "workplace risk relating to work and rest hours is actually multifactorial, and that simplistic regulations based upon only one or two factors have limited value in minimizing this risk." The authors list over 30 factors that determine level of sleepiness and fatigue-related accident risk. They note that the most important factor is circadian phase followed by the number of consecutive number of hours spent continuously awake since the previous sleep episode. Other important factors are the length of the sleep episode, although there can be significant inter-individual variation in terms of cumulative level of sleep deprivation over the past week, the quality of sleep that is obtained, job workload, and moment to moment stimulants or depressants of alertness. The authors use the tale of "two truck drivers" to illustrate the problem with the current (11-hour driving) HOS regulations. In particular, they note the disincentive for drivers to take a nap when they are tired as daytime naps are only allowed to be excluded from a driver's hours on duty in certain situations when the nap is followed by driving, which is in turn immediately followed by an extended period of rest. The authors suggest that the efficacy of "alternative, less punitive, risk management strategies based upon the science of fatigue management" should be demonstrated to provide the basis of regulatory reform and discuss two case studies that their company, *Circadian*, has worked on. The authors suggest alternative paradigms to the current work-rest regulations: fatigue management programs, fatigue risk models, alertness monitors.

Methodology: The authors use a number of case studies to support their arguments that (1) HOS regulations based on only one or two factors have limited value in minimizing risk, (2) there are problems with the current regulations, (3) alternative, less punitive, risk management strategies should be demonstrated to provide the basis of regulatory reform, and (4) the current regulations have an impact on accident litigation. In addition to discussing the various factors that determine level of sleepiness and fatigue-related accident risk, they briefly discuss alternative paradigms to HOS regulations that minimize the risks associated with excessive employee work hours and fatigue.

Scope of Work: Case studies examining the problems with current HOS, regulatory reform, and accident litigation. Also includes a very brief description of alternatives to work-rest regulations such as fatigue management programs, fatigue risk models, and alertness monitors.

Sample Size: n/a

Industry Sector: Truck drivers

Major Limitations: Paper uses case studies to illustrate their views on the limitations of HOS regulations but do not describe in detail the scientific basis for their challenges to work-rest and HOS regulations.

Findings: No specific findings are discussed.

Findings Directly Related to HOS (include page references):

Driver Duration/Crash Risk

No specific findings are discussed.

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: National Transportation Safety Board. “Factors that affect fatigue in heavy truck accidents. Volume 1.” (1995). NTSB Number: SS-95/01. NTIS Number: PB95-917001.

Abstract: This study consists of an analysis of single-vehicle heavy truck accidents by the Safety Board to examine the role of drivers’ patterns of duty and sleep in fatigue-related heavy truck accidents. The Safety Board focused on the sleep patterns of the 96 hours preceding 107 single-vehicle heavy truck accidents in which the driver survived. Fifty-eight percent of the accidents were fatigue-related. Fatigue was considered a probable cause of the accident if the driver was estimated to have been on duty for more than 15 consecutive hours (the current legal limit), and if the driver’s performance involved non-professional, irrational actions such as failure to brake or make appropriate steering maneuvers. A statistical analysis determined that the most important measures predicting a fatigue-related accident in this sample were the “duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident and the split-sleep patterns.” As a result of the study, the Safety Board made safety recommendations regarding sufficient rest provisions (i.e., at least 8 continuous hours of sleep after driving 10 hours or being on duty 15 hours), and scheduling (i.e., prohibit employers, shippers, etc., from scheduling a shipment which would require that the driver exceed the HOS regulations in order to meet the delivery deadline).

Methodology: This study examines the factors that affect driver fatigue rather than the statistical incidence of fatigue. As a result, the Safety Board selected truck accidents that were likely to include fatigue-related accidents, such as single-vehicle accidents that tend to occur at night. As they were specifically interested in the 96-hour duty-sleep history prior to the accident, they focused only on those single-vehicle accidents where the driver survived and could reconstruct the previous 96 hours. Some 113 single-vehicle heavy truck accidents in which the driver survived were investigated. As the 96-hour duty/sleep history was not available for 6 drivers, the authors focused on the data from the remaining 107 single-vehicle heavy truck accidents. A “multivariate statistical analysis (a multiple discriminate analysis) was performed to simultaneously evaluate the relationship of a set of measures of the drivers’ duty and sleep times to the groupings of accidents established by investigator’s determination of probable cause (fatigue-related and nonfatigue-related accidents).”

Scope of Work: An analysis of the 96-hour duty-sleep history prior to 107 single-vehicle heavy truck accidents.

Sample Size: 107 single-vehicle heavy truck accidents

Industry Sector: Heavy truck drivers

Major Limitations: The definition of fatigue may be unduly restrictive, given that it involves driving at least 16 hours, and drivers may be fatigued before this point.

Findings:

1. Of the total, 58% had fatigue as a probable cause, while the remainder were considered not fatigue-related.
2. Nineteen of the 107 drivers stated that they fell asleep while driving.
3. The most important measures in predicting a fatigue-related accident were the duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep patterns. (There were no clinical tests to determine if sleep disorders were a factor.)
4. The truck drivers in fatigue-related accidents were found to have obtained an average of 5.5 hours sleep in the last sleep period prior to the accident. This was 2.5 hours less than the drivers involved in nonfatigue-related accidents (8.0 hours).
5. Truck drivers with split sleep patterns obtained about 8 hours sleep in total in a 24hour time period; however, they obtained it in small segments, on average of 4 hours at a time.

6. A major study conclusion was that "driving at night with a sleep deficit is far more critical in terms of predicting fatigue-related accidents than simply night-time driving."
7. The study found that many of the accident-involved drivers did not recognize that they were in need of sleep and believed that they were rested when they were not. The authors note that "about 80 percent of the drivers involved in fatigue-related accidents rated the quality of their last sleep before the accident as good or excellent."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 2, *"The statistically significant analysis determined that the most important measures in predicting a fatigue-related accident in this sample are the duration of the last sleep period, the total hours of sleep obtained during the 24 hours prior to the accident, and split sleep patterns."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: National Transportation Safety Board. "Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes. Volume 1." (1990). NTSB Number: SS-90/01. NTIS Number: PB90-917002.

Abstract: This study investigated fatal-to-the-driver heavy truck accidents to assess the role that alcohol and other drugs played. The authors looked at a 1-year period (October 1, 1987, through September 30, 1988) in eight states. The authors found that fatigue and fatigue-drug interactions were involved in more fatalities in this study than alcohol and other drugs of abuse alone.

Methodology: The authors examined 182 accident investigations involving 186 heavy trucks that resulted in 207 fatalities, conducted in California, Colorado, Georgia, Maryland, New Jersey, North Carolina, Tennessee, and Wisconsin. As one case was eliminated from the analysis, the study analyses 181 heavy truck accidents involving 185 case vehicles and drivers. Fatigue was considered a probable cause of the accident if the driver was estimated to have been on duty for more than 15 consecutive hours (the current legal limit), and if the driver's performance involved non-professional, irrational actions such as failure to brake or make appropriate steering maneuvers.

The Safety Board contract with the Centre for Human Toxicology (CHT) "provided for toxicological analyses of up to 250 blood samples and 75 urine samples for the drugs in the analytic plan. Safety Board investigators obtained "biological specimens for toxicological testing by CHT in 168, or 91 percent, of the 185 case drivers. No specimens were obtained by Safety Board investigators in 17 cases. In an "additional 16 cases, specimens were of insufficient quantity to test for all drugs on the analytic plan. The Board chose to include in the analysis cases in which CHT testing was carried out for most, but not all, drugs in the analytic plan.

The authors note that "the cutoff concentrations for screen and confirmation tests required by DOT regulation are substantially different from the cutoff concentrations used in this study." "While the DOT sensitivity concentrations apply to urine tests and the NTSB concentrations apply to blood tests, the substantially higher cutoff concentrations for the DOT drug testing regulations are a concern to the Safety Board. High cutoff concentrations are too limiting to allow for a complete performance assessment decrement. In general, urine measurement cannot be used to establish that impairment is present. A drug blood concentration is required. However, under certain circumstances, urine measurement may be used, although with less reliability." Urine was used in approximately 8 of the 168 cases where biological specimens for toxicological testing were available by CHT. The remainder of the cases used blood at NTSB's threshold levels which they noted had substantially lower cutoff concentrations as compared with DOT regulations.

"The different cutoff concentrations indicated the different purposes for which the DOT standards and this study were developed. If the DOT regulation concentrations had been used for post-accident testing in this study, many of the drug of abuse positive (DOAP) drivers would not have been detected."

Scope of Work: An analysis of heavy truck accident investigations during a 1-year period.

Sample Size: 182 accident investigations

Industry Sector: Heavy truck drivers

Major Limitations: Authors do not specify, in synopsis, how they identified when fatigue was a probable cause for an accident.

Findings:

1. "Thirty-three percent of the fatally injured drivers tested positive for alcohol and other drugs of abuse."
2. "There is a significant relationship between drug positive test results and the day of the week. Saturday, Sunday, and Monday are the days with the highest percentage of drug positive tests."
3. "The most frequently cited accident probable cause or factor in fatal-to-the-driver heavy truck accidents was fatigue (57 cases or 31 percent), followed by alcohol and other drug impairment (53 cases or 29 percent). Of the 57 drivers who were fatigued, 19 were also impaired by alcohol and/other drugs."
4. The authors found that there was a strong association between violation of the federal HOS regulations and drug use. In addition, there is a significant relationship between drug positive test results and a shipment deadline for the load being carried.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 3, *"The most frequently cited accident probable cause was fatigue (57 drivers or 31 percent) followed by alcohol and other drug use impairment (53 drivers or 29 percent)."*

Driver Duration

p. 3, *"There is a strong association between violation of the Federal hours of service regulations and drug usage."*

p. 3, *"There is a significant relationship between drug positive test results among professional drivers and a shipment deadline for the load being carried."*

Driver Health

p. 3, "*The driver's medical condition caused, or contributed to 10 percent of the accidents. Over 90 percent of medical condition related accidents involved some form of cardiac incident. This calls into question the effectiveness of the Federal program to assure the proper medical qualification of commercial vehicle drivers."*

p. 3, *"Older drivers are less likely to have tested positive for drugs, but are more likely to have had an incapacitating medical incident."*

Reviewers: Dianne Davis, Alison Smiley

Title: Park, S., Mukherjee, A., Gross, F., and Jovanis, P.P. "Safety implications of multi-day driving schedules for truck drivers: Comparison of field experiments and crash data analysis." Transportation Research Board 2005 Annual Meeting.

Abstract: This paper examines the "effect of multi-day driving and continuous driving (time on task) on crash risk. The study uses pre-existing crash data from the 1980s and measurements from the Driver Fatigue and Alertness Study (DFAS) conducted in the mid-1990s. The research explores "whether a more detailed examination of time of day of driving, particularly over multiple days, indicates associations with crash risk." Night and morning driving and irregular schedules with primarily night and early morning driving, have elevated crash risk of 20 to 70%, 30 to 80%, respectively, compared with daytime driving.

Methodology: Crash data from 1984 through 1985 from a national less-than truckload firm was used for this analysis. At the time of data collection, the company operated coast to coast, with no sleeper berths. The total sample size was 5,050 drivers (i.e., 954 accident-involved drivers and 1,506 non-accident drivers in 1984; 887 accident drivers, and 1,604 non-accident drivers in 1985). Multi-day driving schedules were identified using previous research as well as extracting driving schedules from the DFAS (Wylie et al. 1996). The authors used the data to create two models which were used to examine the data.

Scope of Work: Analysis of pre-existing crash and non-crash data.

Sample Size: 5,050 drivers from a national less-than truckload firm (1984, 1985).

Industry Sector: Less-than-truckload; no sleeper berths

Major Limitations: n/a

Findings:

1. The time of day of driving was significantly associated with increased crash risk. Those drivers who had predominately night and early morning schedules had 20 to 70% higher crash risk than drivers in the baseline regular daytime driving schedule. Overall, 16 of 27 night and early morning driving schedules had elevated risk.
2. Drivers with irregular schedules also have an elevated crash risk (30 to 80% higher).
3. There is a finding of "increased crash risk associated with hours driving, with risk increases of 30-over 80% compared to the first hour of driving. These increases are less than previously reported and are of similar magnitude to the risk increases due to multi-day schedules."
4. The authors note "there is some evidence, although it is far from persuasive, that there may be risk increases associated with significant off-duty time, in some cases in the range of 24 to 48 hours. The implication is that "restart" programs should be approached with caution."

Findings Directly Related to HOS (include page references):

Driver Duration/Crash Risk

p. 14, *"Among the schedules that involved night driving and no days off immediately prior to the day of interest, 9 (schedules C1, C12, C13, C16, C17, C20, C25, C27, C38) out of 12 schedules have elevated risk. Drivers with one or two days off immediately prior to the day of interest have elevated risk in 3 (C7, C8, C32) of 7 cases; and, drivers with irregular schedules have elevated risk in 4 (C9, C39, C40, C42) of 8 cases. These detailed comparisons further highlight the elevated risk posed by night driving compared to the baseline regular daytime driving."*

p. 15, *" There is also evidence that even as much as a 24 hour off-duty period may not be sufficient to alleviate the elevated risk of night and early morning driving. Driving schedules C7 to C9 (averaging about 100 drivers in each group) involve drivers with night and early morning driving and include large amounts of off-duty time one or two days prior to the day of interest; all show elevated crash risk. A similar result appears for schedule C32, although the sample size is only 19 drivers. These findings raise questions about the efficacy of a "restart" period (Smiley and Heslegrave, 1997); there appears to be evidence from this analysis that 24 and perhaps 48 hours may be insufficient, particularly for night and early morning driving. Further, the elevated risk associated with schedules C34 and C35 indicate that two days off duty prior to driving may actually elevate risk, compared to more regular schedules even for day time driving. This may be due to the relative unfamiliarity of driving a heavy vehicle again, or other personal factors, but the evidence exists for those driving at night as well as during the day."*

p. 15, *"Examining the findings in the context of the HOS implemented in 2004 in the U.S., there appears to be support for the changes in regulations that sought more regular schedules. Several of the driving schedules with the highest relative crash risk (e.g., C38, C39, C40) involved irregular schedules. While the sample size in each group was small, the increase in relative risk was large and significant. Previous studies using smaller crash data sets were unable to identify this important effect."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Roehrs, T., Burduvali, E., Bonahoom, A., Drake, C., and Roth, T. "Ethanol and Sleep Loss: A "Dose" Comparison of Impairing Effects." (2003). Sleep, Vol. 26, No. 8, 981–985.

Abstract: This study looks at the effects of sleep loss (0, 2, 4, and 8 hours of sleep loss) as compared with those of ethanol ingestion in 32 adults (ages 21 to 35). "The study was conducted in a mixed design with a between-subject factor, ethanol or sleep loss, and a within-subject factor, dose of either ethanol or sleep loss." The authors found that "sleep loss was more potent than ethanol in its sedative effects but comparable in effects on psychomotor performance. Ethanol produced greater memory deficits, and subjects were less aware of their overall performance impairment."

Methodology: Thirty-two adult volunteers (21 to 35 years old) were randomly assigned to a sleep loss (n = 12) or ethanol (n = 20) group. "The ethanol arm of the study was conducted in a double-blind fashion." Sleep loss participants had 8, 6, 4, and 0 hours time in bed which produced 0, 2, 4, and 8 hours of sleep loss. Participants in the ethanol group ingested 0.0 g/kg, 0.3 g/kg, 0.6 g/kg and 0.9 g/kg ethanol from 8:30 a.m. to 9:00 a.m. after 8 hours of time in bed the previous night. "Each participant received his or her 4 doses of ethanol or sleep loss in a Latin square design with 3 to 7 days between doses." Subjects completed the Multiple Sleep Latency Test (MSLT) (9:30 a.m., 11:30 a.m., 1:30 a.m., 3:30 p.m., and 5:30 p.m.) and a performance battery (10:00 a.m., 12:00 Noon, 2:00 p.m., and 4:00 p.m.), which consisted of memory, psychomotor vigilance, and divided attention tests. "The order in which subjects underwent the ethanol or sleep-loss does was determined by a Latin square design with 3 to 7 days for recovery between doses."

Scope of Work: Study of the risks associated with sleep loss relative to risks of ethanol.

Sample Size: 32 adult volunteers (21 to 35 years old)

Industry Sector: n/a

Major Limitations: n/a

Findings:

1. Sleep loss was "more potent than ethanol in its sedative effects but comparable in effects on psychomotor performance."
2. Ethanol "produced greater memory deficits, and subjects were less aware of their overall performance impairment."
3. Sleep loss was at least as potent as ethanol in its performance-impairing and amnesic effects:
   - Central reaction time was slowed by sleep loss with 8 hours and 6 hours of time in bed (TIB) differing from 0 hours of TIB. In addition, tracking deviations were increased by sleep loss with 8 hours of TIB differing from 0 hours of TIB.
   - Sleep loss produced an increase in lapses (PVT) with the 8 hours of TIB differing from 0 hours of TIB.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 984, *". . . at the studied doses, sleep loss is at least as potent as ethanol in its performance-impairing and amnesic effects and is significantly more potent in its sedative effects."*

p. 984, *"In terms of sedative effects as measured by the MSLT, sleep loss was 2.7 times more potent, meaning that 8 hours of sleep loss is equivalent to 2.16 g/kg of ethanol and 2 hours of sleep loss is equivalent to 0.54 g/kg."*

p. 984, *"In vigilance and divided-attention performance, sleep loss and ethanol were equipotent. In memory, ethanol was slightly more potent."*

p. 984, *"Increasing sleep loss was perceived as increasingly impairing, while only the highest ethanol does was rated as impairing."*

p. 985, *" While sleep loss and ethanol produced equal impairment on the performance tests, at the low and medium ethanol doses, participants did not perceive that impairment. Only at the high dose was performance impairment perceived."*

p. 983, PVT change scores for number of lapses: *"Sleep loss produced an increase in lapses (F=3.19, P<.04) with the 8 hours of TIB differing from 0 hours of TIB."*

p. 984, DAT measures—tracking deviations and central reaction times: *"Central reaction time was slowed by sleep loss (F = 6.20, P < .002), with 8 hours and 6 hours of TIB differing from 0 hours of TIB. The ingestion of ethanol did not alter central reaction time . . . Tracking deviations were increased by sleep loss (F = 4.35, P < .01), with 8 hours of TIB differing from 0 hours of TIB. Ethanol ingestion also increased tracking deviation with the 0.3-g/kg dose differing from the 0.9-g/kg dose. Both ethanol (F = 9.25, P < .01) and sleep loss (F = 4.32, P < .05) produced linear dose effects. Ethanol ingestion and sleep loss did not differ in effects on tracking deviations, which the relative potency analyses also reflected (NS)."*

p. 984, *"While both performance tests used in this study have previously been shown to be sensitive to sleep-deprivation effects, these tests are relatively short (10 and 15 minutes), and longer tests may have revealed a greater potency of sleep loss compared to ethanol. As to MSLT sensitivity, in previous studies from this laboratory, the MSLT has consistently been found to be more sensitive to the effects of ethanol compared to performance testing."*

p. 984, *"Ethanol and sleep loss were equipotent in impairing psychomotor performance at the studies does. Tracking deviation on the DAT were increased to the same extent by both ethanol and both sleep loss, while the reaction-time parameters on this task did not show consistent effects. Subjects often concentrate on 1 component of the task at the expense of the other, which in this case was the tracking component. On the PVT, which does not require divided attention, reaction times were affected. But, interestingly, on this task, both ethanol and sleep loss slowed the fastest reaction times, parenthetically to the same degree and in a dose-related linear fashion, while lapses and the slowest reaction times were not consistently affected. This is not supportive of the "lapse" hypothesis of sleep-deprivation effects, which suggests lapses in performance occur as one becomes sleepier. What these data show is that best performance is degraded."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Alison Smiley, Dianne Davis

Title: Saccomanno, F.F, Shortreed, J.H., and Yu, M. (1996). "Effect of Driver Fatigue on Commercial Vehicle Accidents." In Truck Safety: Perceptions and Reality (ed. Saccomanno, F. and Shortreed, J.) (1995). The Institute for Risk Research, University of Waterloo, Waterloo, Canada.

Abstract: A Canadian study, by Saccomanno et al. (1996), used several different databases to determine accident risk associated with different driving times. Databases included police accident reports, a commercial vehicle survey of driver demographics, work hours, and routes. The focus of the study was fatigue-related accidents, defined as single-vehicle accidents that occurred between midnight and 8:00 a.m. or single-vehicle accidents where the driver was recorded as being at fault. Fatigue-related accident risk was significantly higher for routes characterized by long driving times, that is, where the 85th percentile driving time was 9.5 hours or longer. There were more single-vehicle accidents at night (assumed to be associated with fatigue) than during the day. There was a higher proportion of single-vehicle accidents on routes typified by long driving times. In remote regions, the nighttime single-vehicle accident rates were particularly high—13 times greater than for more populated areas in the daytime.

Methodology: This study used "surrogate measures of fatigue derived from the accident data and surveys of drivers who reported on their driving time, to compare accident rates between locations and times for different types of fatigue." Four databases from the Province of Ontario were used in this analysis: Ontario motor vehicle accident data, Ontario Highway Inventory Management System, Ontario Traffic Volume Information System, and Ontario Commercial Vehicle Survey (CVS). The CVS data, which provided information on commercial vehicles surveyed at 75 representative locations in the provincial highway network, were key to the fatigue analysis as these data provided direct evidence on the hours of driving from the last rest stop for each sampled truck driver in the traffic stream.

Scope of Work: Database analysis to compare accident rates between locations and times for different types of fatigue.

Sample Size: 1988–1989 truck accident data

Industry Sector: Trucks

Major Limitations: n/a

Findings:

1. Fatigue-related accident risk was significantly higher for routes characterized by long driving times, that is, where the 85th percentile driving time was 9.5 hours or longer.
2. There were more single-vehicle accidents at night (assumed to be associated with fatigue) than during the day. The results confirm the presence of circadian fatigue.
3. There was a higher proportion of single-vehicle accidents on routes typified by long driving times.
4. In remote regions, the nighttime single-vehicle accident rates were particularly high—13 times greater than for more populated areas in the daytime. This points to the effect of circadian fatigue on truck accident rates appearing to be additive to the effect of industrial fatigue.

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 170, *"Longer hours of driving without rest result in significantly higher fatigue accident rates. An appreciable increase in rates (i.e., a pronounced discontinuity in the relationship) was found to occur for more than 9.5 hours of driving without proper rest."*

p. 171, *"The results of the study confirm the presence of circadian fatigue in the Ontario truck accident data by indicating higher fatigue-related accident rates at nighttime as compared to daytime over the entire highway network (northern and southern regions)."*

p. 171, *"The effect of circadian fatigue on truck accident rates appears to be additive to the effect of industrial fatigue. In the northern region, where longer driving is expected to result in industrial fatigue, the nighttime single vehicle accident rate is 3.3 times higher than the daytime rate. A similar relationship was found in the southern region with a ratio of 2.3 night accident rates to day accident rates."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Van Dongen, Hans P.A., Maislin, G., Mullington, J.M., and Dinges, D. "The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation." (2003*). Sleep,* Vol. 26, No. 2, 117–126.

Abstract: Forty-eight adults participated in a laboratory study of chronic sleep restriction or total sleep deprivation. Subjects in the chronic restriction experiment were randomly assigned one of three sleep doses (4 h, 6 h, or 8 h time in bed per night), which were maintained for 14 consecutive days. Subjects in the total sleep deprivation experiment had 3 nights without sleep (0 time in bed). Both experiments had 3 baseline (pre-deprivation) days and 3 recovery days. The researchers found that "chronic restriction of sleep periods to 4 h or 6 h per night over 14 consecutive days resulted in significant cumulative, dose-dependent deficits in cognitive performance on all tasks." Lapses in behavioral alertness and reductions in working memory performance, in the 4 h condition, reached levels equivalent to those observed after 2 nights without sleep. After 14 days of sleep restriction, cognitive throughput performance was equivalent to that observed after 1 night without any sleep.

Methodology: Forty-eight healthy adult subjects participated in a chronic sleep restriction experiment or a total sleep deprivation experiment. Both experiments began with 1 adaptation day and 2 baseline days with 8 h sleep opportunities. In the chronic sleep restriction experiment, this was followed by randomization to 8 h, 6 h or 4 h sleep periods (time in bed ending at 0730) for 14 days. In the total sleep deprivation experiment, subjects were kept awake for 88 h. Both experiments concluded with 3 recovery days. Subjects in all experimental conditions (e.g., psychomotor vigilance task, Stanford Sleepiness Scale, Karolinska Sleepiness Scale) underwent neurobehavioural assessments every 2 h during scheduled wakefulness. In addition to neurobehavioural measures, polysomnographic (PSG) recordings were made during the third baseline sleep period and during 10 of the 14 restricted sleep periods.

Scope of Work: Chronic sleep restriction and total sleep deprivation.

Sample Size: 48 healthy adults (ages 21 to 38)

Industry Sector: n/a

Major Limitations: n/a

Findings:

1. "Chronic restriction of the nocturnal sleep period to either 6 h or 4 h per day for 14 days resulted in significant cumulative performance deficits relative to the 8 h sleep period condition."
2. "Subjects allowed an 8 h sleep period per night displayed only minor, non-significant increases in lapses of behavioral alertness over the 14 days." . . . "In contrast, subjects in the 4 h sleep period condition displayed escalating numbers of lapses in behavioral alertness and decreasing cognitive accuracy and speed across the 14 days. The magnitude of changes in performance over days of sleep restriction in the 6 h sleep period was between that observed in the 8 h and 4 h sleep period conditions."
3. "In the 4 h sleep period condition, lapses in behavioral alertness and reductions in working memory performance reached levels equivalent to those observed after 2 nights without sleep. Cognitive throughput performance after 14 days of sleep restriction was equivalent to that observed after 1 night without any sleep. Subjects in the 6 h sleep period condition also reached levels of impairment equivalent to those observed after 1 night of total sleep loss for lapses in behavioral alertness and working memory performance."
4. "Chronic restriction of the nocturnal sleep period to either 6 h or 4 hr per day for 14 days resulted in a relatively small but significant build-up of subjective sleepiness, as measured with the Stanford Sleepiness Scale (SSS) relative to the 8 h sleep period condition."

5. "Cumulative total sleep time increased near-linearly over days in the 8 h, 6 h and 4 h sleep period conditions.
6. "Cumulative sleep loss over 14 days in the 4 h sleep period condition was significantly greater than cumulative sleep loss over 3 days in the total sleep deprivation condition."
7. The findings of this study contradict the "core sleep" hypothesis. The "core sleep" hypothesis asserts that "core" or "obligatory" sleep occupies the first part of the night and serves to "repair the effects of waking wear and tear on the cerebrum." In this hypothesis, all sleep obtained beyond this core sleep (especially that dominated by SWS and SWA) duration is considered to be "optional" or "facultative" sleep. As SWS and SWA were conserved among sleep restriction conditions in this study, the finding that cumulative cognitive impairment developed "in cerebral functions at 4 h and 6 h time for sleep per night indicates that the current threshold of 6 h for core sleep duration cannot be correct. If 6 h sleep per day were the maximum duration of sleep required to maintain normal cerebral functions, cumulative cognitive performance deficits should not have developed in that condition. Thus, the results from the present study do not support a functional distinction between "core" and "optional" sleep."

Findings Directly Related to HOS (include page references):

Fatigue/Alertness

p. 122, *". . . the two modes of sleep loss yielded similar maximum deficits for PVT performance but chronic sleep restriction resulted in much greater cumulative sleep loss than did 3 days of total sleep deprivation.*

p. 124, *"Contrary to earlier, uncontrolled studies of prolonged sleep restriction, this experiment yielded convergent findings of sleep dose-response effects on all three cognitive performance functions. Sleep periods chronically limited to 4 h and 6 h per night progressively eroded the effectiveness of psychomotor vigilance performance, working memory performance and cognitive throughput performance, providing convergent evidence for the adverse effects of chronic sleep restriction on cognitive functions . . . Claims that humans adapt to chronic sleep restriction within a few days on the other hand, are not supported by the present findings."*

p. 124, *"Since chronic restriction of sleep between 4 h and 6 h per night for 14 days produced cognitive performance deficits comparable to those found under conditions of 1 to 2 days of total sleep deprivation, it appears that even relatively moderate sleep restriction—if sustained night after night—can seriously impair waking neurobehavioural functions in healthy young adults."*

p. 124, *"We conclude that the effects of sleep chronically limited to 4 h and 6 h per night on cognitive performance appear to reflect progressive neurocognitive dysfunction in systems underlying sustained attention and working memory."*

p. 124, *". . . unlike performance measures, sleepiness ratings appeared to show adaptation to chronic partial sleep deprivation . . . These findings for subjective sleepiness suggest that once sleep restriction is chronic, subjects either cannot reliably introspect with regard to their actual sleepiness levels, or as long as they are receiving at least approximately 4 h of sleep nightly they do not experience a sense of sleepiness anywhere near the levels found for total sleep deprivation."*

p. 124, *"Measures of sleep physiology were less responsive to chronic sleep restriction than were waking neurobehavioural functions. The primary effects on sleep architecture were immediate, overall reductions in the amounts of stages 1, 2 and REM sleep."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Williamson, A., Friswell, R. and Feyer, A.M. "Fatigue and performance in heavy truck drivers working day shift, night shift or rotating shifts." (2004). National Transportation Commission.

Abstract: This field study was designed to compare the impact of day and night shift rosters on subjective fatigue, performance, and the sleep and work of drivers. In addition to permanent day shift and night shift drivers, drivers working alternating weeks of day and night shifts participated in the study. Drivers participated for 2 weeks to "attempt to obtain a reliable sample of their work." Over the 2 weeks, each driver was measured repeatedly. In addition to completing tests of concentration and reaction speed, drivers completed performance tests, kept diaries of their work, break, and sleep times and completed ratings of their subjective fatigue. Actigraph data was also collected to provide objective measures of the timing and quality of their sleep. The researchers found that while the night shifts made drivers feel more tired than day shifts, it did not "produce significantly poorer performance, suggesting that night drivers can manage their fatigue."

Methodology: Fifty-four Australian drivers participated in the study: 22 permanent day shift drivers, 21 permanent night shift drivers, and 11 rotating shift drivers. Each driver was repeatedly measured over a 2-week period. Drivers completed concentration and reaction speed tests at the start of the first shift of the study fortnight (baseline), and at the end of the last shift in week 1 and week 2. Drivers also self-administered the Simple Reaction Time test as well as the Macworth Clock Vigilance task (shortened version) at the start and end of each shift during the fortnight, as well as at the start of one midshift break in each shift. In addition to these performance tests, drivers kept diaries of their work, break, and sleep times and completed ratings of their subjective fatigue and quality of sleep. Actigraphy data was also collected to complement the self-report measures.

Scope of Work: Impact of day and night shift rosters on subjective fatigue, performance, and sleep and work on long-haul drivers.

Sample Size: 54 male professional long-distance drivers (22 permanent day shift drivers, 21 permanent night shift drivers, and 11 rotating shift drivers)

Industry Sector: Professional long-distance drivers

Major Limitations: Two practical and methodological issues limited the current study: driver recruitment and missing data. The authors had to relax their initial recruitment specifications to select groups of drivers on the basis that they did a particular shift. Instead the final sample included "any driver working permanent day or night shifts that were rostered to be 11 or more hours long." "As a result, in order to obtain a sufficiently large sample of drivers who did day shifts, the study also included drivers who worked rotating day shifts." According to the authors, "missing data posed a serious problem for the current study, limiting the type of data analyses that could be conducted and the strength of conclusions that could be drawn."

Findings:

1. Over a typical workweek of five consecutive 10- to 12-hour shifts, there was a significant increase in subjective ratings of fatigue by all drivers.
2. Between the start and end of each shift within the workweek, rated fatigue also increased. Permanent night shift drivers and drivers on rotating night shifts showed greater increases than day drivers. However, it is important to note that the permanent night shift drivers had lower fatigue ratings at the start of their shift than permanent day drivers.
3. The study failed to find significantly poorer performance for night drivers as compared with day drivers. Simple reaction time test performance tended to be slower at the end of the week for all drivers. Similarly, there were no differences between day and night drivers on subjective fatigue ratings. The results of the PVT suggest a slowing in reaction

speed across the work week for night drivers while day drivers showed faster response time at the end of the week; however, this was non-significant. While the authors note that this lack of difference could be due to the testing time for night drivers, who tended to complete their end-of-week tests around dawn, this would not explain the absence of differences between rotating day drivers and night shift drivers who completed their end-of-week testing earlier in the morning during the circadian low.

4. The authors note that an alternative explanation for failing to find the predicted effect for night drivers could be that the "work-rest pressures were more important than the circadian influences experienced in night work." All of the drivers worked similar long hours (e.g., 50 to 55 hours arranged in five 10- to 12-hour shifts), which may eclipse any effects due to circadian or time of day influences. Drivers had between 4 and 6 hours sleep between work shifts. The authors note that all of the drivers in this study "were being affected by restricted sleep and that any differential effects of night work may be overshadowed by this effect." In addition, they note that night shift drivers performed as well as day shift drivers as they are experienced professional drivers "who are well-suited to cope with the demands of the road transport industry by organizing their work-rest."
5. Night shift drivers worked longer shifts than day shift drivers and spent much more of their working time driving than day shift drivers "which might predict that night shifts would be more tiring than day shifts." However, the authors suggest that night shift drivers may have performed as well as day shift drivers as they may be "especially tolerant of fatigue or skilled at managing fatigue" and because they organize their sleep differently (e.g., napping in the hours before their first shift of the week) which may partly explain how they could maintain performance. For example, the authors noted that night drivers "endeavored to capitalize on the sleep propensity influences of the circadian rhythm by getting as much sleep as they could as close as possible to the early morning circadian trough when sleep is most likely."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 43, *"For permanent shift drivers, 2 (group) by 2 (occasion) repeated measures MANOVA showed a significant occasion effect, with the overall subjective fatigue rating higher at the end of the working week compared to baseline. Although the mean scores suggest a greater increase in rated fatigue across the week for night shift drivers, no statistically significant difference in overall subjective fatigue was found between day shift drivers and night shift drivers."*

p. 45, *"Repeated measures MANOVA showed that permanent day and night shift drivers did not differ on any of the Simple Reaction Time task measures. RT tended to be higher at the end-of-week compared to baseline but there was no significant interaction on any performance measures between type shift and test occasion. These results indicate that both day and night drivers showed slowing of reaction speed over the week but to an equal extent."*

p. 46, *"On average, there was no significant difference between permanent day shift drivers and permanent night shift drivers on any of the Mackworth Clock Vigilance performance measures."*

p. 48, *"There were no significant differences in any PVT performance measures between the beginning of the week and the end of the selected study week. Analysis of interaction effects showed two non-significant trends for interaction between driver group and test occasion."*

Driver Health

No significant findings or assumptions concerning impact on health.

Reviewers: Dianne Davis, Alison Smiley

Title: Williamson, A., Feyer, A.M., Friswell, R., and Leslie, D. "Strategies to combat fatigue in the long-distance road transport industry: Stage 2 evaluation of alternative work practices." (2004). National Transportation Commission.

(Note: This study was covered in Part I in Williamson et al. (1996) "The impact of work practices on fatigue in long distance truck drivers." *Accident Analysis & Prevention,* Vol. 28, No. 6, 709–71. The following presents findings not covered in Part I.)

Abstract: A repeated measures design was used in this study. Twenty-seven subjects participated in each of three work practices: staged trip driving (two drivers from different points of origin meet mid-trip and exchange loads, within HOS regulations), flexible trip driving (single driver, trip scheduled without reference to HOS regulations) and single trip driving (single driver, within HOS regulations) A range of fatigue measures were used including performance tests, physiological, and subjective measures. The authors found that "a 10–12 hour trip is tiring no matter how the work is organized, and that the effects of accumulated fatigue may overshadow the effects of fatigue on a single 10–12 hour trip."

Methodology: A sample of 27 drivers participated in a repeated measures design. Each driver participated in three work practices: staged driving (within HOS), flexible trip driving (outside HOS), and single trip driving (within HOS). The three methods were compared on a 10- to 12-hour route between Sydney and Melbourne. Each driver was assessed before the trip, on the road, and after the trip for all three work practices. A range of fatigue measures were used including performance tests (cognitive performance tests, on-road performance test), physiological (e.g., hear rate), and subjective measures (e.g., Stanford Sleepiness Scale). Monitoring of drivers' cognitive and physiological functioning, as well as monitoring of their driving performance, were on-road measures. "The equipment was designed to obtain data in real time without interfering with the driving task, and allowing the driver to use his regular vehicle." In addition to a questionnaire (e.g., demographics, driving experience) administered prior to the trip, drivers were asked to complete a trip diary including driving details (e.g., breaks) as well as their ratings of feelings of fatigue.

Scope of Work: A repeated measures design comparison of trips within HOS regulations: staged trip driving and single trip driving; and driving outside HOS: flexible trip driving.

Sample Size: 27 long-distance truck drivers (mean age: 38.4; driving experience: 15.9 years)

Industry Sector: Professional long-distance drivers

Major Limitations: The authors note that the analysis of the results of this study was hampered to some extent by missing data, particularly in the data collected during the trip. When only a section of data is missing in a repeated measures design, cases can be rejected and the "power of the study to detect differences between groups when differences actually exist" is weakened. As a result, this may lead to more conservative conclusions.

Findings:

1. Drivers experienced higher subjective fatigue at the end of the trip compared with the beginning for all trip types.
2. While staged drivers reported higher fatigue at the beginning of staged trips compared with the other trip types, this "most likely reflects the cumulative impact of the previous week's work which was typical of the schedules routinely worked by these drivers. Fatigue levels were also higher for staged drivers at the end of the trip compared to the ratings at the end of the trip for the other trip types, suggesting that if a driver starts the trip more tired, he is likely to be more fatigued at the end of the trip."
3. "The results of this study show that overall there was relatively little difference between the trip types in the effects on the drivers' performance."

4. Some performance tests did show poorer performance for staged strips compared to control trips. These results suggested that when doing staged trips drivers did not handle tasks requiring prolonged attention as well as when they were doing the other trip types. The conclusion cannot be drawn, however that the unique characteristics of staged driving created this inferior performance."
5. "For the vigilance and unstable tracking tasks, drivers showed poorer performance when on staged trips than on either of the other trips."
6. "Performance for the CFF test also revealed poorer performance by drivers on staged trips, but only for the beginning of the trip."
7. There were no differences related to type of trip or the time in the trip that the test occurred for the simple reaction time test or for the on-road reaction time test.
8. "On staged and control trips, heart rate decreased across the trip, indicating decreasing alertness. In contrast, when on flexible trips heart rates were much slower at the beginning of the trip, but increasing such that by the end of the trip they had much faster heart rate than the other trip types. This suggests that when on flexible trips, drivers had lower alertness, based on the heart rate measure, at the beginning of the trip but their alertness increased by the end of the trip."

Findings Directly Related to HOS (include page references):

Driver Fatigue/Alertness

p. 3, *"Drivers experienced higher subjective fatigue at the end of the trip compared to the beginning for all trip types indicating that the experience of driving for 10 to 12 hours was tiring, no matter how the work was organized."*

p. 3, *". . . drivers reported higher fatigue at the beginning of staged trips compared to the other trip types. This most likely reflects the cumulative impact of the previous week's work which was typical of the schedules routinely worked by these drivers."*

p. 3, *"Fatigue levels were also higher for staged drivers at the end of the trip compared to the ratings at the end of the trip for the other trip types, suggesting that if a driver starts the trip more tired, he is likely to be more fatigued at the end of the trip."*

p. 6, *"Factors other than experiences during a 12 hour trip must be considered as causes of fatigue in these drivers. The results of this study suggest that factors leading to chronic fatigue, such as heavy work load over the past few days may account for differences in fatigue levels of drivers. Of the three types of trips, the staged trips were most vulnerable to the effects of work in the past week due to their order in the study. The impact of aspects of work organization was clearly revealed in the finding that on staged trips drivers were much more tired at the very start of the trip and remained so at the end of the trip. Given that drivers are fatigued by 12 hour trips, irrespective of how they are driven, it is essential that they start fresh and fit to drive. Further, it seems likely that if 12 hour trips and the work organization surrounding them render drivers vulnerable to fatigue, the impact of work organization on trips involving even longer hours will also be considerable."*

Driver Duration

p. 5, *"Differences between driving types were not sufficient to account for changes in fatigue or performance in this study. All drivers reported more fatigue over the trip, but not all drivers showed poorer performance. It seems that the 12 hour trip is relatively immune to any effects of differences in work practices. It is possible that studying such relatively short trips will not provide clear findings. It may be that longer trips are needed to assess the effect of the differences between these three work practices. It is certainly noteworthy that flexible trips produced no worse an outcome than either of the other two ways of doing the same trip. In fact, a more exhaustive evaluation of flexibility, where drivers have the* *opportunity to learn about manipulating the timing of work and rest during several trips, might reveal that flexibility is of benefit in managing fatigue."*

p. 105, *"There is little evidence that allowing drivers the freedom to organize the work-rest schedules of their own trips affected their performance. Drivers on flexible trips showed few differences on any of the cognitive or on-board performance tests compared to control trips. It seems that the requirement to comply with the regulated work-rest arrangement does not enhance the drivers' cognitive functioning or work performance, nor does it reduce the amount of fatigue that drivers report. It should be noted, however that flexible drivers did tend to select work-rest schedules which were quite similar to the regulated working hours. It would be interesting to determine whether this similarity persists when the trip is longer."*

Driver Health

p. 5, *"Even though studies have linked general health and lifestyle to increased fatigue, the design of this study allowed us to rule out factors relating to individual drivers such as level of experience, general health and lifestyle as causes of fatigue in this group of drivers. Undoubtedly 12 hours of driving produces fatigue, but this study suggests that the fatigue does not occur because of factors like poor driver preparation, poor rest and break behavior, driving route, or their motivation to complete their trip."*

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation