TRANSPORTATION RESEARCH SYNTHESIS

Monitoring Motor Vehicle Driver Fatigue

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT. This TRS does not represent the conclusions of either CTC & Associates or MnDOT.

Introduction

MnDOT staff are required to complete a wide range of driving tasks, and MnDOT is interested in determining how fatigue affects an individual's ability to drive safely. To better understand the relationship between fatigue and unsafe driving, MnDOT would like to learn more about the methods, tools and technologies used to predict, diagnose and monitor driver fatigue.

To meet this need, CTC & Associates conducted a review of recently published research and supporting documents that examine the characteristics of driver fatigue and how to predict and monitor it.

Summary of Findings

There is a wealth of information on the topic of fatigue monitoring—especially with regard to commercial drivers—and the research highlighted in this report is only a sampling of the available information. It is also important to note that advancements in technology make for a rapidly changing landscape.

The information in this report is organized by topic to allow for a more comprehensive and concise review of each topic area. Citations in each topic area may include both domestic and international research as well as research focused on different vehicle classes (commercial and passenger).

This report is divided into the following sections:

- Training Resources
- General Research on Fatigue Monitoring Technologies

- Out-of-Vehicle Fatigue Monitoring
- In-Vehicle Fatigue Monitoring
- Fatigue Management in Winter Operations
- Techniques to Avert Fatigue

Training Resources

Two resources for commercial driver training materials provide an excellent starting point for the discussion of fatigue monitoring research. Commercial Motor Vehicle (CMV) Driving Safety, a website sponsored by the National Surface Transportation Safety Center for Excellence at the Virginia Tech Transportation Institute, offers a PowerPoint presentation (included in this report as Appendix A) that presents a concise summary of the pros and cons of some of the fatigue monitoring technologies addressed later in this report. These measures include:

- Driver-based measures such as electroencephalography (EEG), which monitors the brain's electrical activity; electrocardiography (ECG), which measures heartbeat signals; and ocular measures that monitor eye closures and eye blinks.
- Vehicle-based measures that monitor lane drift (the vehicle's position relative to lane markings) and steering wheel inputs (as the driver becomes more sleepy, less frequent steering corrections are made).

The North American Fatigue Management Program (NAFMP) provides a "comprehensive approach for managing commercial driver fatigue" through its website. NAFMP's training presentation on fatigue management technologies (included in this report as Appendix B) provides extensive information about the most promising technologies available, comparing the measures and providing data on their potential effectiveness.

General Research on Fatigue Monitoring Technologies

The publications in this section address a range of issues related to driver fatigue:

- A 2013 Australian publication identifies factors that may contribute to or increase the risk of fatigue and offers suggestions for controlling that risk.
- A 2011 journal article addresses the challenges and opportunities presented by the technologies used to assess fatigue. The authors offer their description of an ideal system.
- A 2009 report from the Federal Motor Carrier Safety Administration (FMCSA) focuses on recent developments in two areas: mathematical models that predict operator alertness and performance at different times, and vehicle-based operator alertness monitoring technologies that assess behavioral characteristics.
- In a 2009 journal article, researchers examine the effectiveness of existing and emerging technologies for addressing task-related forms of driver fatigue. The authors distinguish sleep-related fatigue, which results from prolonged wakefulness or troughs in the circadian rhythm (the 24-hour cycle of physical, mental and behavioral changes), from task-related fatigue, which is caused by mental overload or underload.

Out-of-Vehicle Fatigue Monitoring

While most of the fatigue-monitoring technologies presented in this report are in-vehicle systems associated with the driver or the vehicle, this section highlights a few examples of out-of-vehicle technologies, including:

- *Fitness for duty*. These often simple-to-use tests are typically administered before a driver begins a shift. A 2013 journal article describes a fit-for-duty test based on eye movements. Postural balance is proposed in a 2012 journal article as a fitness-for-duty test for fatigue. Researchers note that postural

balance may be a viable option for assessing fatigue associated with time of day, but may not be useful for assessing fatigue associated with extended wakefulness.

- *Testing in the field*. These field tests are designed to help assess fatigue during a driver's shift, such as during a roadside stop by a patrol officer. Postural control is mentioned again in a 2014 journal article as a potential roadside test using a computerized force platform. In a December 2012 Nebraska Department of Roads report, researchers isolate three categories of factors that hold promise for identifying fatigue in the field—physiological factors, driver facial characteristics and steering cues—and propose a plan for future research that would develop a toolkit that includes forms for recording data and devices for measuring a driver's physiological and facial characteristics in the field.

In-Vehicle Fatigue Monitoring

Eye Indicators
Four of the five studies in this section address the use of PERCLOS, or PERcent CLOSed, to assess eye blinks and identify fatigue. (PERCLOS is the percent of time when the eye is 80 to 100 percent closed during a short time window.) One of these studies seeks to dispute the superiority of PERCLOS as a measurement to detect fatigue. In this study, researchers found that fusing eye-tracking data with measurements of physiological signals provided greater amounts of fatigue information than the PERCLOS measure alone. A 2013 journal article adds a new element to the discussion of the use of PERCLOS to assess fatigue—the use of a smartphone to capture images of drivers, then apply computer vision algorithms to detect and track the face and eye of the driver.

Monitoring Heart Rate
The publications cited in this section address the use of an ECG sensor embedded in the steering wheel of a car to monitor a driver's heartbeat, which provides an indication of the driver's level of fatigue. One of the studies augmented the steering wheel sensor with an ECG sensor installed on the driver's seat back.

Monitoring Brain Waves
The SmartCap system described in this section uses a cap that measures brain waves to identify fatigue in drivers and report results in real time.

Multichannel Systems
The research reports and articles in this section describe the use of more than one measurement to assess fatigue. Some researchers refer to this as data fusion, while others distinguish fatigue monitoring systems as single-channel (one fatigue indicator) or multichannel (more than one fatigue indicator). Some researchers note that multichannel systems are more effective than single-channel systems because the strength of one indicator at any given time can offset the weakness of another.

Vehicle-Based Measures
In the two articles cited in this section, vehicle-based measures assess lane position, which monitors the vehicle's position as it relates to lane markings, to identify driver fatigue, and gather steering wheel movement data to classify fatigue from slight to strong. In one research project, researchers note the advantages of using steering behavior to detect fatigue, highlighting the continuous nature of this nonintrusive and cost-effective monitoring technique.

Fatigue Management in Winter Operations

Only two publications that specifically address fatigue in snowplow drivers were identified. An April 2014 report sponsored by the Clear Roads pooled fund project offers a recent and extensive assessment of fatigue-related literature, discusses the technologies available for fatigue monitoring, and presents recommendations for winter maintenance managers seeking to better manage fatigue among their drivers. The driver-centric fatigue monitoring measures discussed in the report include:

- *Fitness for duty.* These tests, which often measure hand-eye coordination and/or reaction time, assess a driver's cognitive ability before the driver begins a shift.
- *In-vehicle monitoring.* These real-time, vehicle-based monitoring technologies assess such factors as physiological signals, psychomotor skills or lane position to predict or monitor fatigue. Systems can be single-channel or multichannel, with the latter combining two or more predictors of fatigue.
- *Crash avoidance systems.* These systems use steering input to detect the changes in steering behavior that may indicate driver fatigue.

In the second publication highlighted in this section, a Canadian report examines the fatigue management processes of the six private contractors providing snow clearing services to Alberta, Canada. Rather than assessing the tools and technologies used to monitor fatigue, this report offers advice for managing fatigue in snowplow drivers.

Techniques to Avert Fatigue

Rather than predicting or monitoring fatigue, the techniques described in two 2014 journal articles are designed to improve a driver's ability to remain alert. In the first article, researchers sought to develop a strategically timed secondary verbal task to improve alertness. The second article examines the use of a 20 Hz mechanical vibration applied to the driver's right heel during simulated monotonous driving to assess its impact on driving performance.

Detailed Findings

Training Resources

The training materials in this section provide an excellent starting point for a review of the technologies, tools and practices used to monitor commercial driver fatigue. The two organizations highlighted below offer training resources that provide excellent summaries of the technologies available to monitor fatigue and the implications of their use. Many of the monitoring measures introduced in these resources are addressed in greater detail in subsequent sections of this report.

Driver Drowsiness and Fatigue, CMV Driving Safety, National Surface Transportation Safety Center for Excellence, Virginia Tech Transportation Institute.
http://cmvdrivingsafety.org/modules/driver-drowsiness-and-fatigue/
This Web page provides an overview of a training module that addresses driver drowsiness and fatigue. A PowerPoint presentation, "Driver Drowsiness/Fatigue: A Wake-up Call," included as **Appendix A** to this report, can be accessed from this Web page. The presentation begins with a quiz to help distinguish driver drowsiness from fatigue. The discussion that follows presents a good summary of the pros and cons of some of the fatigue monitoring technologies addressed later in this report. Included in the discussion that begins on slide 25 of the presentation are:

- Driver-based measures such as electroencephalography (EEG), which monitors the brain's electrical activity, and ocular measures that monitor eye closures and eye blinks.

- Vehicle-based measures that monitor lane drift (the vehicle's position relative to lane markings) and steering wheel inputs (as the driver becomes more sleepy, less frequent steering corrections are made).

The presentation highlights these key findings from fatigue-related research:

- Drowsy or fatigued driving is difficult to detect. Physiological measures may be difficult to implement, and differences among individual drivers need to be accounted for.

- No single detection measure is uniformly successful. Confounding factors include weather, eyewear and individual differences.

- One possible solution is data fusion, which integrates fatigue-related information gathered from multiple sources.

North American Fatigue Management Program: A Comprehensive Approach for Managing Commercial Driver Fatigue, NAFMP Steering Committee.
http://www.nafmp.org/en/
From the website: The NAFMP is designed to address the issue of driver fatigue with a comprehensive approach that includes:

- Information on how to develop a corporate culture that facilitates reduced driver fatigue.
- Fatigue management education for drivers, drivers' families, carrier executives and managers, shippers/receivers, and dispatchers.
- Information on sleep disorders screening and treatment.
- Driver and trip scheduling information.
- Information on Fatigue Management Technologies.

Related Resources:

North American Fatigue Management Program (NAFMP), Office of Research and Technology, Federal Motor Carrier Safety Administration, *TRB 93rd Annual Meeting; Federal Motor Carrier Safety Administration Analysis, Research, and Technology Forum*, January 14, 2014.
http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/North%20American%20Fatigue%20Management%20Program%20(NAFMP).pdf
This presentation provides a brief history and description of NAFMP and highlights website content.

Guidelines and Materials to Enable Motor Carriers to Implement a Fatigue Management Program:
Implementation Manual, North American Fatigue Management Program, undated.
http://files.nafmp.com/nafmp/download/implementation_manual_en.pdf
Included in this manual is a discussion of NAFMP's online training program, which includes Module 10: Fatigue Monitoring and Management Technologies. This one-hour session provides an introduction to fatigue monitoring technologies; identifies the most promising technologies available; and provides comparisons and data to describe the potential effectiveness of the measures. The PowerPoint presentation used in this training session can be accessed from the organization's download page (see the links for "Module 10 (MS Powerpoint)" available at http://www.nafmp.org/en/downloads.html). The presentation (with narration included in the notes portion of each slide) is included as **Appendix B** to this report.

General Research on Fatigue Monitoring Technologies

In addition to providing recommendations for controlling the risk of fatigue, the publications below address some of the critical issues associated with human interaction with monitoring systems, recent developments in mathematical models that predict operator alertness and vehicle-based technologies that assess behavioral characteristics, and the methods and technologies used to detect and respond to task-related fatigue.

Guide for Managing the Risk of Fatigue at Work, Safe Work Australia, November 2013.
http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/825/Managing-the-risk-of-fatigue.pdf
While this publication does not address the technologies associated with identifying fatigue, it does highlight ways to identify factors that may contribute to or increase the risk of fatigue and offer suggestions for controlling the risk of fatigue (see page 9 of the report; page 11 of the PDF). Case studies in Appendix D provide examples of ways to implement control measures in managing the risk of fatigue in the workplace.

"The Challenges and Opportunities of Technological Approaches to Fatigue Management," Thomas J. Balkin, William J. Horrey, R. Curtis Graeber, Charles A. Czeisler and David F. Dinges, *Accident Analysis & Prevention*, Vol. 43, Issue 2, pages 565-572, March 2011.
Citation at http://www.sciencedirect.com/science/article/pii/S0001457509003200
From the abstract: There are a number of different strategies to mitigate the effects of fatigue in transportation and other occupational settings. Many are centered on regulatory or organizational approaches, such as work scheduling restriction and employer screening practices. While these generally benefit safety and productivity, there are clearly limitations to these approaches. Technologies that objectively detect or predict operator fatigue may be used to effectively complement or even supplant organizational or regulatory approaches. Over the past decade and a half, there have been considerable advances in relevant technologies, including onboard devices that monitor drivers' state or level of performance as well as devices that predict fatigue in advance of a work cycle or trip. In this paper, we discuss the challenges and opportunities for technological approaches to fatigue management, beginning with a discussion of the "ideal" system, followed by some of the general issues and limitations of current technologies. We also discuss some of the critical and outstanding issues related to the human interaction with these systems, including user acceptance and compliance. Finally, we discuss future directions in next generation technology for fatigue management.

An Evaluation of Emerging Driver Fatigue Detection Measures and Technologies, Lawrence Barr, Stephen Popkin and Heidi Howarth, Federal Motor Carrier Safety Administration, June 2009.
http://ntl.bts.gov/lib/34000/34700/34775/FMCSA-RRR-09-005.pdf
As the Executive Summary notes, the "major objective of this paper is to review and discuss many of the activities currently underway to develop unobtrusive, in-vehicle, real-time drowsy driver detection and fatigue-monitoring/alerting systems."

The study focuses on recent developments in two areas:

- Mathematical models that predict operator alertness and performance at different times. Factors involved in the assessment include the amount of sleep obtained or missed, circadian factors (the 24-hour cycle of physical, mental and behavioral changes) and workload.

- Vehicle-based monitoring technologies that assess behavioral characteristics of the driver such as eye gaze, eye closure, head position and movement, and heart rate.

Chapter 3, Summary and Assessment of Fatigue Detection and Monitoring Technologies, begins on page 12 of the report (page 26 of the PDF). This chapter includes case studies of currently available or soon-to-be-available fatigue detection technologies for application in a commercial driving environment. Summaries of each device include a discussion of the device's background, functionality, and use; relevant research findings; and future directions for device development.

"Driver Fatigue: The Importance of Identifying Causal Factors of Fatigue When Considering Detection and Countermeasure Technologies," Jennifer F. May and Carryl L. Baldwin, *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 12, Issue 3, pages 218-224, May 2009.
Citation at http://www.sciencedirect.com/science/article/pii/S1369847808001009
From the abstract: Driver fatigue is an ill-defined term in the literature. It has been broadly used to refer to a wide range of driver states, each with different causal mechanisms. Technologies currently exist which enable detection of driver fatigue and interventions that have the potential to dramatically reduce crash probability. The successful implementation of these technologies depends on the cause and type of fatigue experienced. Sleep-related (SR) forms of driver fatigue result from accumulated sleep debt, prolonged wakefulness or troughs in the circadian rhythms. SR fatigue is resistant to most intervention strategies. Conversely, technologies for detecting and countering task-related (TR) fatigue (caused by mental overload or underload) are proving to be effective tools for improving transportation safety. Methods of detecting and counteracting the various forms of driver fatigue are discussed. Emphasis is placed on examining the effectiveness of existing and emerging technologies for combating TR forms of driver fatigue.

Out-of-Vehicle Fatigue Monitoring

While most of the fatigue-monitoring technologies presented in this report are in-vehicle systems associated with the driver or the vehicle, this section highlights a few examples of out-of-vehicle technologies, including:

- *Fitness for duty*. These often simple-to-use tests are typically administered before a driver begins a shift.

- *Testing in the field*. The testing protocols described in the citations below require further development but may show promise as tools for assessing fatigue in drivers during a shift, such as during roadside stops by patrol officers.

Fitness for Duty

Karolinska Sleepiness Scale (KSS), Notice of Copyright text, Common Data Elements project, National Institute of Neurological Disorders and Stroke.
http://www.commondataelements.ninds.nih.gov/Doc/NOC/Karolinska_Sleepiness_Scale_NOC_Email.pdf

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> *Note*: References to the Karolinska Sleepiness Scale appear in the citations that follow in this section and in subsequent sections of this report. The KSS is an easy-to-administer subjective measure of sleepiness. Some researchers have compared the effectiveness of the KSS against objective measures of fatigue.

From the PDF:

Short Description of Instrument:
The Karolinska Sleepiness Scale (KSS) is a self-report scale that measures the subject's drowsiness and is frequently used in studies measuring subjective sleepiness.

Scoring:
It is a 9-point verbally anchored scale going from 'extremely alert' to 'extremely sleepy–fighting sleep'.

"Fit-for-Duty Test for Estimation of Drivers' Sleepiness Level: Eye Movements Improve the Sleep/Wake Predictor," Christer Ahlstrom, Marcus Nyström, Kenneth Holmqvist, Carina Fors, David Sandberg, Anna Anund, Göran Kecklund and Torbjörn Åkerstedt, *Transportation Research Part C: Emerging Technologies*, Vol. 26, pages 20-32, January 2013.
Citation at http://www.sciencedirect.com/science/article/pii/S0968090X1200099X
From the abstract: The aim of this study was to develop a fit-for-duty test based on eye movement measurements and on the sleep/wake predictor model (SWP, which predicts the sleepiness level) and evaluate the ability to predict severe sleepiness during real road driving. Twenty-four drivers participated in an experimental study which took place partly in the laboratory, where the fit-for-duty data were acquired, and partly on the road, where the drivers sleepiness was assessed….Future improvements of a fit-for-duty test should focus on how to account for individual differences and situational/contextual factors in the test, and whether it is possible to maintain high sensitive/specificity with a shorter test that can be used in a real-life environment, e.g. on professional drivers.

"Can a Simple Balance Task Be Used to Assess Fitness for Duty?" Charli Sargent, David Darwent, Sally A. Ferguson and Gregory D. Roach, *Accident Analysis & Prevention,* Vol. 45, Supplement, pages 74-79, March 2012.
Citation at http://www.sciencedirect.com/science/article/pii/S0001457511002673
From the abstract: Postural balance has been proposed as a fitness for duty test for fatigue, but it is largely untested. Therefore, the purpose of this study was to examine the impact of sleep loss, extended wakefulness and circadian phase on postural balance. Fourteen male participants spent 10 consecutive days in a sleep laboratory, including three adaptation days and eight simulated shiftwork days. To simulate a quickly rotating roster, shiftwork days were scheduled to begin 4 h later each day, and consisted of a 23.3-h wake episode and a 4.7-h sleep opportunity. Every 2.5 h during wake, balance was measured while standing as still as possible on a force platform with eyes open for one minute, and eyes closed for one minute. Subjective sleepiness was assessed using the Karolinska Sleepiness Scale….These results indicate that postural balance may be a viable tool for assessing fatigue associated with time of day, but may not be useful for assessing fatigue associated with extended hours of wake.

Testing in the Field

"Feasibility of Force Platform Based Roadside Drowsiness Screening—A Pilot Study," Pia Forsman, Ilmari Pyykkö, Esko Toppila and Edward Hæggström, *Accident Analysis & Prevention*, Vol. 62, pages 186-190, January 2014.
Citation at http://dx.doi.org//10.1016/j.aap.2013.09.015

From the abstract: Previous research on driver drowsiness detection has focused on developing in-car systems that continuously monitor the driver while driving and warn him/her when drowsiness compromises safety. In occupational settings a simple test of postural control has showed sensitivity to work shift induced fatigue in drivers. Whether the test is feasible for surveillance purposes in roadside settings is unknown. The present research sought to evaluate the feasibility of using a force platform test of postural control as a breathalyzer-like drowsiness-test at the roadside. Seventy-one commercial drivers stopped by at the authors' measurement sites and volunteered to participate in the study. The authors tested postural control with a computerized force platform, on which the drivers stood eyes open while it sampled body center-of-pressure excursions at 33 Hz for 30 s and scored postural control as the area of the 95% confidence ellipse enclosing the excursions. The drivers also completed the Karolinska Sleepiness Scale (KSS) and the authors recorded each driver's wake up time, time on task, and time of testing. Five of the seventy-one drivers exhibited significantly poorer postural control than their peers ($P = 0.03$). The wake up times and times on task for these five drivers indicated that they were on a night shift schedule or had a long time on task. Furthermore, their postural control and KSS scores correlated ($r = -0.88$, $P = 0.04$), whereas the scores did not correlate for their peers ($r = 0.10$, $P = 0.48$). These results indicate that the force platform test identified drivers, whose impairment in postural control was drowsiness-related. Specifically, the test identified the few drivers in this roadside sample whose wake- and work histories resembled a night shift schedule. In this kind of roadside setting, with a demographically heterogeneous group and interindividual differences in people's responses to drowsiness, it suggests that the method, further developed, may provide a drowsiness test for roadside surveillance.

Diagnostic Tools for Identifying Sleepy Drivers in the Field, Matthew Rizzo, Jon Tippin and Nazan Aksan, Iowa Department of Transportation, May 6, 2013.
http://www.iowadot.gov/research/reports/Year/2013/fullreports/diagnostictoolssleepydriversFinalreport_2013.pdf
From the Executive Summary on page 15 of the report:

> Our goal was to identify those indicators that [were] reliably and consistently sensitive to amount of sleep deprivation in unselected populations and distinguished different populations and then to identify a subset of indicators that could be recommended for inclusion into the Fatigued Driving Evaluation Checklist to be used by officers in field evaluations of CMV [commercial motor vehicle] drivers.

Recommendations begin on page 16 of the report:

> Given the evidence from this study and others, our recommendations inform broader policy and incentives that encourage compliance with mandated duty cycles. In terms of monitoring compliance with sleep–duty cycles, we would recommend that CMV drivers wear actigraphy watches to monitor their sleep cycles. Watch data can be downloaded quickly and efficiently in a field evaluation to examine whether a CMV driver had adequate amount of sleep. Based on Phase I of this study, we would also recommend inclusion of cognitive testing during field evaluations only if CMV drivers' baseline performance on PVT [Psychomotor Vigilance Task] collected when they are well-rested and motivated to perform at their best is kept on record and available to DOT officers.

Characteristics of Fatigued Commercial Motor Vehicle Drivers—A Preliminary Investigation, Aemal Khattak and Carrie Mohlman, Nebraska Department of Roads, December 2012.
http://www.transportation.nebraska.gov/mat-n-tests/research/Traffic/Final%20Report%20M319.pdf
In an effort to give state patrol officers the tools needed to identify fatigued commercial vehicle drivers in the field, researchers sought to identify and correlate easily observable characteristics of drivers to different levels of fatigue. The project included a literature review to identify the characteristics of fatigued drivers, and a nationwide telephone survey of state patrol agencies to assess their practices in identifying fatigued driving.

Results of the literature review isolated three categories of factors that hold promise for identifying fatigue in the field:

- Physiological factors (heart rate and respiratory pattern).
- Driver facial characteristics (rapid eye blinking and eyelid droop).
- Steering cues (slow drifting followed by fast correction).

Other factors, including in-vehicle technologies such as seat pressure, were deemed impractical for use by patrol officers in the field.

Page 3 of the report (page 14 of the PDF) provides an excellent summary of the literature on fatigue in commercial drivers. Page 10 of the report (page 21 of the PDF) provides a graphical summary of the fatigue characteristics identified in the literature review, with citations noted, for each category (driver facial characteristics, physiological, in-vehicle, roadway characteristics, steering cues and driving-related).

Researchers proposed a plan for future research that would develop a toolkit for measurement of fatigue. The proposed toolkit would be based on the three categories of factors identified above and would include field measurement techniques and criteria for identifying fatigue. Researchers envision a toolkit that includes paper or electronic forms for recording data and devices for measuring a driver's physiological and facial characteristics.

Note: Dr. Aemal Khattak, principal investigator for this research project, was contacted about the follow-up project to develop the toolkit described in the December 2012 report. Dr. Khattak is not aware of any ongoing or follow-up research on this issue in Nebraska, though he noted that Nebraska State Patrol and Nebraska Department of Roads remain interested in the topic.

Contact: Dr. Aemal Khattak, Associate Professor, Department of Civil Engineering, University of Nebraska–Lincoln and Nebraska Transportation Center, 402-472-8126, khattak@unl.edu.

In-Vehicle Fatigue Monitoring

The citations that follow are organized in the following sections:

- Eye Indicators
- Monitoring Heart Rate
- Monitoring Brain Waves
- Multichannel Systems
- Vehicle-Based Measures

Eye Indicators

Four of the five studies below address the use of PERCLOS, or PERcent CLOSed, to assess eye blinks and identify fatigue. PERCLOS is the percent of time when the eye is 80 to 100 percent closed in a short time window.

"Eye Indicators and Driving Fatigue Research Based on Driving Simulator," Feihu Li and Xuesong Wang, *Proceedings of the 14th COTA International Conference of Transportation Professionals*, pages 2463-2471, June 2014.
Citation at http://dx.doi.org/10.1061/9780784413623.235
From the abstract: Driving fatigue is an important cause of traffic accidents. Numerous researchers have investigated the relationship between fatigue and eye indicators. Most research focuses solely on comparing eye indicators between awake and fatigue. However, driver fatigue is a gradually accumulated procedure, and different fatigue states have different indicators and different effects on driving safety. This study was undertaken to find the rules of eye indicators changing when the driver was under different fatigue. Based on the Tongji 8 degree-of-freedom (DoF) Driving Simulator, 15 eye indicator samples were collected using the Smart Eye. The driver's fatigue was divided into five levels, including: awake, mild fatigue, moderate fatigue, severe fatigue and extreme fatigue. The results showed that all eye indicators increased slightly before the driver enters a mild fatigue state. However, at a level of severe fatigue, the percentage of eyelid closure (PERCLOS), variable coefficient of pupil diameter and blink duration increased significantly, but blink frequency decreased slightly.

"Physiological and Accident Prevention Effects of Sleep Alert Systems: Comparative Study of Eye Closure and Heart Rate Based Alarms," Shin Osuga and Kazuo Hiraki, *Proceedings of the 20th ITS World Congress*, 2013.
Citation at http://trid.trb.org/view/2013/C/1323162
From the abstract: Driver drowsiness is one of the important issues in our traffic society today. A lot of methods to estimate drowsiness and alert systems have been proposed so far. In this study, the authors executed a driving simulator experiment in order to clarify the effects of two kinds of drowsy driver alert systems, which are based on eye closure duration and heart rate fluctuation. Driving information and answers of questionnaires were analyzed to evaluate the effects of the systems. Results of the questionnaire analysis showed that an alert system based on eye closure is much more appropriate and effective as a drowsy driver alert system. But there were no statistical differences on driving information such as the numbers of rear-end collisions and lane departures.

"Fatigue Detection Using Smartphones," J. He, S. Roberson, B. Fields, J. Peng, S. Cielocha and J. Coltea, *Journal of Ergonomics*, Vol. 3, Issue 3, 2013.
http://omicsgroup.org/journals/fatigue-detection-using-smartphones-2165-7556.1000120.pdf
In this paper, the authors describe a working prototype that uses an Android smartphone or an iPhone that monitors visual indicators of driver fatigue to provide real-time fatigue detection. The authors note that most computer vision-based technologies require devoted cameras and computer processors, which increases the price of the technology. Use of the smartphone platform holds promise for making fatigue detection systems more affordable and portable.

In the prototype, the front camera of a smartphone is used to capture images of drivers. Computer vision algorithms are used to detect and track the face and eye of the drivers. Head nod, head rotation and eye blinks are then detected as indicators of driver fatigue. For this study, researchers applied PERCLOS to assess eye blinks. In a simulated driving study, researchers identified significant differences in the frequency of head nod, head rotation and eye blinks in drowsy drivers as compared to when the drivers were attentive.

Researchers note the current limitations of the use of mobile technology:
- The computer vision algorithms use battery life quickly. Drivers are expected to use this technology with a car charger to power the smartphone. Advancements in battery technology may address this concern.

- Eye detection is difficult for drivers wearing sunglasses. When eye detection is not possible, head nods and rotations can still be used to detect fatigue.

"PERCLOS: An Alertness Measure of the Past," Udo Trutschel, Bill Sirois, David Sommer, Martin Golz and Dave Edwards, *Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, pages 172-179, 2011.
Citation at http://trid.trb.org/view/2011/C/1107678
From the abstract: PERCLOS (percentage of eye closure) was introduced as an alertness measure. Some years later, it was claimed to be superior in fatigue detection to any other measure, including the general Eye-Tracking Signal (ETS) and even EEG recordings. This study will show that this is not the case. To put things into the prospective a fair and objective comparison between PERCLOS, the general ETS and EEG/EOG has to be established. To achieve this purpose, a protocol was established to investigate the fatigue detection capabilities of PERCLOS, ETS, and EEG/EOG in a simple two class discrimination analysis using an ensemble of Learning Vector Quantization (LVQ) networks as a classification tool. Karolinska Sleepiness Scale (KSS) and Variation of Lane Deviation (VLD) were used in order to obtain independent class labels, whereas KSS provided subjective alertness labels while VLD provided objective alertness labels. The general ETS and the fused EEG/EOG measures contain substantially greater amounts of fatigue information than the PERCLOS measures alone. These conclusions were found to be valid for all three commercially available infrared video camera systems that were utilized in the study. The data utilized in the discrimination analysis were obtained from 16 young volunteers who participated in overnight experiments in the real car driving simulation lab at the University of Schmalkalden.

The Drowsy Driver Warning System Field Operational Test: Data Collection Methods, Richard J. Hanowski, Myra Blanco, Akiko Nakata, Jeffrey S. Hickman, William A. Schaudt, Maria C. Fumero, Rebecca L. Olson, Julie Jermeland, Michael Greening, G. Thomas Holbrook, Ronald R. Knipling and Phillip Madison, National Highway Traffic Safety Administration, September 2008.
http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2008/810035.pdf
In this project, researchers tested a driver fatigue monitor (DFM) developed by Attention Technologies, Inc., that estimates PERCLOS. Researchers note that a primary limitation of the DFM is its inability to operate during the daytime or with drivers who wear glasses.

Researchers collected data from commercial truck drivers in a field test conducted in a naturalistic driving environment. Forty-six trucks were instrumented with a data acquisition system that collected over 100 data variables, including the PERCLOS output from the DFM and driving performance data such as lane position, speed and longitudinal acceleration. Researchers also obtained video footage and questionnaires completed by participating drivers.

Two focus group meetings gathered feedback from drivers participating in the study. Drivers noted that they could rely on the DFM at night, but not at dusk and dawn. Too many false alarms were presented, sometimes every few minutes. Recommendations to improve the DFM include:
- Reducing the false alarm rate.
- Separating the DFM camera from the DFM controls. Participants recommended placing the camera at the upper center area of the windshield, and putting the DFM controls in the same area where vehicle controls are located on the dashboard to mimic the built-in controls.
- Using a smaller camera to minimize the visual area blocked by the system.
- Using two or three DFM cameras in the cab or around the windshield to expand the viewing area.
- Using a few additional light sensors to moderate sensitivity to ambient light level (e.g., street lights, work zone lights, reflected headlights) and reduce the false alarm rate.

Monitoring Heart Rate

The citations in this section address the use of fatigue-detection technologies to monitor the heart rate of the operators of passenger vehicles. The technology used in these applications could be adapted to monitor the heart rate of commercial vehicle drivers as well.

"Driver Fatigue and Drowsiness Monitoring System With Embedded Electrocardiogram Sensor on Steering Wheel," Sang-Joong Jung, Heung-Sub Shin and Wan-Young Chung, *IET Intelligent Transport Systems*, Vol. 8, Issue 1, pages 43-50, February 2014.
Citation at http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6720253
From the abstract: Real time driver health condition monitoring system with drowsiness alertness was proposed. A new embedded electrocardiogram (ECG) sensor with electrically conductive fabric electrodes on the steering wheel of a car was designed to monitor the driver's health condition. The ECG signals were measured at a sampling rate of 100 Hz from the driver's palms as they stay on a pair of conductive fabric electrodes located on the steering wheel. Practical tests were conducted using an embedded ECG sensor with a wireless sensor node, and their performance was assessed under non-stop 2 h driving test. The ECG signals were measured and transmitted wirelessly to a base station connected to a server PC in personal area network environment. The driver's health condition such as the normal, fatigued and drowsy states was analysed by evaluating the heart rate variability in the time and frequency domains.

Real-Time Nonintrusive Detection of Driver Drowsiness, Xun Yu, Intelligent Transportation Systems Institute, Center for Transportation Studies, University of Minnesota, May 2009.
http://www.its.umn.edu/Publications/ResearchReports/pdfdownloadl.pl?id=1126
Researchers developed a real-time, nonintrusive driver drowsiness detection system. Conductive fabric ECG sensors installed on the steering wheel and driver's seat measure the heartbeat signal from the driver's palms and the driver's back. Researchers note that heart rate variability (HRV), which is determined by measuring the driver's heartbeat signals with the ECG sensor, is important in identifying the stages of waking through sleepiness.

Driving simulation tests showed that the proposed sensors were able to continuously monitor the driver's heart rate and that HRV shows promise as an indicator for drowsiness detection. Researchers identified the following limitations during the course of the project:

- The driver must put both hands on the steering wheel for the sensor to detect and measure the ECG signal. Gloves also interfere with signal detection.
- The ECG sensor on the driver's seat back is very sensitive to noise.
- Because each individual has a unique HRV pattern, future research is needed to create individualized criteria for drowsiness detection.

"Driver Sleepiness Level Detection Based on the Heart Rate Variability," Yasuhiko Nakano, Ayu Miyakawa, Satoshi Sano and Hideo Katoh, *15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting*, 2008.
Citation at http://trid.trb.org/view.aspx?id=900333
From the abstract: This paper reports on a study of technology that can be used to monitor vehicle drivers based on a frequency analysis of their heart rate variability and power spectrum density. The authors first developed a system to detect driver sleepiness. Using a steering wheel sensor to get a heartbeat signal, they can detect the early signs of drowsiness and cope with individual differences through a unique coordinated analysis of the two axes denoted by the driver's excitement level and awareness level. This monitor was compared with video images of the drivers under simulation conditions, to test the validity of the heart rate monitoring system. The authors conclude that this technology can successfully be used to detect drivers' sleepiness before critical situations arose.

Monitoring Brain Waves

The product described below uses a baseball cap-like measuring device to monitor brain waves and assess drowsiness in vehicle drivers.

SmartCap, EdanSafe Pty Ltd.
http://smartcap.com.au/smartcap-overview/
SmartCap provides real-time measurements of fatigue in vehicle drivers and heavy equipment operators. Developed with the support of the Australian mining industry to improve employee safety, SmartCap uses brain waves measured through a baseball cap to calculate and measure drowsiness. Information about fatigue is displayed to the user on a fixed or mobile device.

More information is available at http://smartcap.com.au/faq/. Also from the website:

> The SmartCap, a baseball cap containing sophisticated sensors concealed in the cap lining, uses an operator's brain wave (EEG) information to calculate a measure of drowsiness, which is wirelessly communicated to a display in-cab, or to any Bluetooth enabled device. This has been made possible by the development of small sensors capable of reading EEG through hair, without the need for any scalp preparation. With the look and feel of a typical baseball cap, the SmartCap overcomes the operator acceptance problems experienced by sites that in the past have implemented camera or response based technologies.

Multichannel Systems

These systems employ more than one measurement to assess fatigue. Some researchers refer to this as data fusion, while others distinguish systems as single-channel (one fatigue indicator) or multichannel (more than one fatigue indicator). Some researchers note that multichannel systems are more effective than single-channel systems because the strength of one indicator at any given time can offset the weakness of another.

***Research in Progress*: Drowsy Driver Mitigation System**, Federal Motor Carrier Safety Administration.
http://www.fmcsa.dot.gov/research-and-analysis/research/drowsy-driver-mitigation-system

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Note: While completion of the project's final report was scheduled for September 2013, a final report does not appear to be publicly available online.

The goal of this project is to "develop and test a prototype system to unobtrusively detect and alert drowsy, distracted, and aggressive drivers prior to performance degradation." In Phase I of the project, Transecurity LLC developed a multivariable drowsy driver mitigation system that combines multiple indicators of drowsiness and alertness into a composite drowsiness score. Advisory and warning messages are presented to the driver, and supplemental notifications to fleet management are also supported. The second phase of the project involves completing development and commercialization of the system. Tasks include:

- Eye and head tracking software development.
- Continued algorithm development to detect behaviors of interest and combine them into a composite drowsiness score.
- Development of an appropriate human/machine interface.

"Drowsiness and Fatigue Sensing System Based on Driver's Physiological Signals," José Solaz, Helios de Rosario, Paulo Gameiro and Daniel Bande, *Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment*, April 2014.
http://tra2014.traconference.eu/papers/pdfs/TRA2014_Fpaper_19586.pdf
From page 3 of the conference paper:

> The proposed solution is a nonintrusive sensing system of driver's heart activity and respiration, embedded in the seat cover and the safety belt of a car. The rhythm of heart beats, specially heart rate (HR) and heart rate variability (HRV), are good indicators of concentration and wakefulness (Lal and Craig, 2001), whereas the decrement of respiration rate has been also been proved to be correlated with increasing fatigue in monotonous driving (Milosevic, 2010), such that slow and deep breathing can indicate a relaxed resting state (Hadjileontiadis, 2006). The HARKEN system will detect the mechanical effect such physiological activity, filter and cancel the noise and artefacts expected in a moving vehicle (vibration and body movements), and calculate parameters like the intervals between heart beats, or the amplitude and frequency of the respiration signal, which will be delivered in a readable format to integrate it in a fatigue detector (see figure 3).

Researchers cite two innovative elements of their work:

- The conventional electrodes used to monitor physiological signals are replaced by smart textile materials. These materials are composed of a combination of fibers and yarns with electrical properties, supported by the standard fabric used in the seat cover and safety belt.
- The redundancy of physiological and dynamic measures of the driver's body, which allows for the use of data fusion strategies to improve reliability.

Development and Assessment of a Driver Drowsiness Monitoring System, Darrell Bowman, Richard J. Hanowski, Andrew Alden, Santosh Gupta, Doug Wiegand, Stephanie Baker, Laura M. Stanley and Walter Wierwille, Federal Motor Carrier Safety Administration, December 2012.
http://ntl.bts.gov/lib/51000/51200/51285/Development-and-Assessment-of-a-Driver-Drowsiness-Monitoring-System-508.pdf
Researchers developed a prototype driver drowsiness monitoring system that included sensors to detect eye closure and lane position. The prototype provided a system status for both factors and a warning when system thresholds were breeched. An on-road evaluation under varying conditions identified the need for both sensors with an integrated approach to the analysis, noting that the strength of one sensor was able to overcome weaknesses of the other sensor as needed.

Conclusions and recommendations begin on page 125 of the report (page 147 of the PDF). Future research needs include:

- Collecting real-world commercial driving data to determine the appropriate thresholds to be used in future drowsiness detection systems.
- Additional work to ensure driver acceptance of an integrated monitoring system. For example, there are placement considerations. As the report indicates, "mounting the unit directly in front of the driver may cause the sensor view to be obscured by the steering wheel, especially with the newer extended tilt/telescoping steering columns being offered by commercial truck original equipment manufacturers. However, the current eye closure technology requires the unit to be mounted directly in front of the driver to provide the best view of the driver's eyes."
- Expanding the capabilities of a system that monitors drowsiness and fatigue to also address driver inattention.

Non-Contact Driver Drowsiness Detection System, Xiong (Bill) Yu, Final Report for Safety IDEA Project 17, Safety IDEA Program, Transportation Research Board, July 2012.
http://onlinepubs.trb.org/Onlinepubs/IDEA/FinalReports/Safety/IDEA_Safety_17.pdf
Researchers in this Innovations Deserving Exploratory Analysis (IDEA) project developed a noncontact sensing platform to monitor the ECG and EEG signals of drivers. As indicated in other studies, this report's authors note that research has found physiological signals like the ECG are good indicators of drowsiness. The system also detects eye blinking, which the authors note is another good indicator of fatigue. The noncontact sensing platform developed in this study improves on systems requiring contact with the driver because it does not interfere with normal driver operations and is more feasible for long-term use.

Using a signal processing algorithm, the system can obtain the driver's heart rate, heart rate variability and breath frequency in real time. Researchers suggest that the sensor could be used for railroad train operators and large truck and bus drivers. A provisional patent application was filed through the Office of Technology Transfer, Case Western Reserve University, in spring 2011, with the goal of developing the technology into a "robust in-vehicle drowsiness monitoring system to improve operator safety."

"An In-Vehicle Physiological Signal Monitoring System for Driver Fatigue Detection," Ye Sun, Xiong Yu, Jim Berilla, Zhen Liu and Guangxi Wu, *3rd International Conference on Road Safety and Simulation*, 2011.
http://onlinepubs.trb.org/onlinepubs/conferences/2011/RSS/1/Sun,Y.pdf
From the abstract: This paper describes the development of an in-vehicle measurement system that monitors the physiological signals (i.e., heart rate, heart rate variation, breathing and eye blinking) of drivers. These physiological signals will be utilized to detect the onset of driver fatigue, crucial for timely applying drowsiness countermeasures. Fatigue driving is one of the most significant factors causing traffic accidents. Clinic research has found physiological signals are good indicators of drowsiness. A conventional bioelectrical signal measurement system requires the electrodes to be in contact with human body. This not only interferes with the normal driver operation, but also is not feasible for long term monitoring purpose. This study developed a non-contact sensing platform that can remotely detect bioelectrical signals in real time. With delicate sensor electronics design, the bioelectrical signals associated with electrocardiography (ECG), breathing and eye blinking can be measured. The current sensor can detect the Electrocardiography (ECG) signals with an effective distance of up to 30 cm away from the body. It also provides sensitive measurement of physiological signals such as heart rate, breathing, eye blinking etc. The sensor performance was validated on a high fidelity driving simulator. Digital signal processing algorithms has been developed to decimate the signal noise and automate signal analyses. The characteristics of physiological signals indicative of driver fatigue, i.e., the heart rate (HR), heart rate variability (HRV), breath frequency and eye blinking frequency, can be determined. A robust drowsiness indicator is being developed by coupling the multiple physiological parameters to achieve high reliability in drowsiness detection.

"Fast Microsleep and Yawning Detections to Assess Driver's Vigilance Level," Nawal Alioua, Aouatif Amine, Mohammed Rziza and Driss Aboutajdine, *Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, pages 365-372, 2011.
Citation at http://trid.trb.org/view/2011/C/1108734
From the abstract: This paper proposes fast methods to identify drowsiness and fatigue using respectively microsleep and yawning detections. In this study, the proposed scheme begins by a face detection using local Successive Mean Quantization Transform (SMQT) features and split up Sparse Network of Winnows (SNoW) classifier. After performing face detection, the novel approach for eye/mouth detection, based on Circular Hough Transform (CHT), is applied on eyes and mouth extracted regions. The authors' proposed methods works in real-time and yield a high detection rates whether for drowsiness or fatigue detections.

"Driving Fatigue Identification Method Based on Physiological Signals," Zhe Mao, Xin-Ping Yan and Chao-Zhong Wu, *Plan, Build and Manage Transportation Infrastructure in China: Seventh International Conference of Chinese Transportation Professionals*, pages 341-352, 2008.
Citation at http://trid.trb.org/view/2008/C/921461
From the abstract: This study aims to identify driving fatigue through a driver's physiological signals. Physiological signals, including heart rate, skin conduction, electromyogram, skin temperature and respiration, were collected on eight simulating experiments with 1Hz sample rate. Then wavelet transform was used to find feature vectors and a two-step fuzzy cluster analysis was developed to classify the different levels of fatigue, including alertness, a transitional phase and fatigue. Compared with the experimental data, 93.75% of the normal and abnormal states and 63.64% of the transitional and fatigue levels had been correctly identified. The results showed that such a method could provide an effective way to detect a driver's alert state level. To improve the reliability of this algorithm, more physiological signals are needed and an impersonal metrics must be used to judge the actual state of the driver.

"A Study of Driver Fatigue Detection System for Heavy Trucks and Fatigue Management System," Haruyuki Nakayama, *15th World Congress on Intelligent Transport Systems and ITS America's 2008 Annual Meeting*, 2008.
Citation at http://trid.trb.org/view.aspx?id=892157
From the abstract: This paper reports on a study undertaken to evaluate a driver fatigue detection system for drivers of heavy trucks. The detection system was developed under test-driving conditions that include 24 hours of driving on a test track at Nihon University and 12 hours of driving on a national highway in Japan. The level of driver fatigue is shown as a Driver Fatigue Index (DFI). After the detection system was installed in the heavy trucks used in this study, various experiments aimed at establishing practical usage parameters for the system were conducted under actual operating conditions. These included truck positioning data (verified by GPS), three-dimensional acceleration levels, the vehicle's operating speed, the driver's heart rate, body surface temperature, and DFI. The collected data was transmitted automatically to the researchers by a mobile packet transmission system. The results of the study were displayed on a web page used by operations managers to monitor driver fatigue levels for road safety purposes. The authors conclude that unconscious movements, such as a driver rotating his neck, can indicate that the driver has begun to feel tiredness. This tendency may vary depending on each individual driver, but the researchers determined that driver fatigue can be detected using this method. This method also offers the benefit of not requiring the installation of special sensors on the driver's body or the video monitoring of the driver's face. Instead, driver fatigue state can be monitored using a sensor attached to the driver seat.

Vehicle-Based Measures

Vehicle-based measures typically use steering wheel movement data or an assessment of lane position (the vehicle's position relative to lane markings) to identify driver fatigue.

"Modeling Fatigue Level by Driver's Lane-Keeping Indicators," Chuan Xu, Xuesong Wang and Xiaohong Chen, *Proceedings of the Fourth International Conference on Transportation Engineering,* pages 2282-2288, October 2013.
Citation at http://dx.doi.org/10.1061/9780784413159.331
From the abstract: A study using the Tongji high-fidelity driving simulator investigated the relationship between fatigue and lane-keeping indicators. During about 1 hour monotonous highway driving for each driver, driving data of 30 participants including lateral position, speed, and steering wheel movement data were collected. Meanwhile, Karolinska Sleepiness Scale (KSS) was recorded to measure driver's fatigue scale. To estimate driver's lane keep ability appropriately, standard deviation of lateral position (SDLP), lane crossing time-space area (LCTSA), standard deviation of steering wheel speed (SDSWS), and steering wheel reversal rate (SWRR) were measured. While controlling for other contribution factors including driving speed and road alignment, a multilevel ordered logistic model was established using Winbugs software. The research found that experienced

drivers have a higher threshold for KSS. SDLP, SDSWS, and SWRR show significant positive relation to fatigue level. Another finding is that the differences between two adjacent KSS thresholds increase with KSS value.

"Steering Wheel Behavior Based Estimation of Fatigue," Jarek Krajewski, David Sommer, Martin Golz, Udo Trutschel and David J. Edwards, *Proceedings of the 5th International Driving Symposium on Human Factors in Driving Assessment, Training and Vehicle Design*, pages 118-124, 2009.
Citation at http://trid.trb.org/view/2009/C/918391
From the abstract: This paper examined a steering behavior based fatigue monitoring system. The advantages of using steering behavior for detecting fatigue are that these systems measure continuously, cheaply, non-intrusively, and robustly even under extremely demanding environmental conditions. The expected fatigue induced changes in steering behavior are a pattern of slow drifting and fast corrective counter steering. Using advanced signal processing procedures for feature extraction, we computed 3 feature set in the time, frequency and state space domain (a total number of 1251 features) to capture fatigue impaired steering patterns. Each feature set was separately fed into 5 machine learning methods (e.g. Support Vector Machine, K-Nearest Neighbor). The outputs of each single classifier were combined to an ensemble classification value. Finally the authors combined the ensemble values of 3 feature subsets to a of meta-ensemble classification value. To validate the steering behavior analysis, driving samples are taken from a driving simulator during a sleep deprivation study (N = 12). The authors yielded a recognition rate of 86.1% in classifying slight from strong fatigue.

Fatigue Management in Winter Operations

The publications in this section address fatigue in one of MnDOT's major service areas—winter maintenance operations. The April 2014 Clear Roads report described below offers a recent and extensive assessment of fatigue-related literature, discusses the technologies available for monitoring, and presents recommendations for winter maintenance managers seeking to better manage fatigue among their drivers. A Canadian report offers general advice for managing fatigue in snowplow drivers.

Environmental Factors Causing Fatigue in Equipment Operators During Winter Operations, Matthew C. Camden, Alejandra Medina Flintsch, Jeffrey S. Hickman, James Bryce, Gerardo Flintsch and Richard Hanowski, Clear Roads Pooled Fund, April 7, 2014.
http://clearroads.org/wp-content/uploads/dlm_uploads/11-05-Factors-Causing-Fatigue-Final-Report_MnDot.pdf

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Note: The Clear Roads Pooled Fund was contacted about whether any follow-up research is planned in this area. While the pooled fund members have indicated significant interest in a follow-up project, there is nothing scheduled at this time.

Clear Roads initiates new research projects annually. The number of partner agencies in the pooled fund determines the level of funding available for these projects each year. In 2014, the Clear Roads Technical Advisory Committee voted to fund 10 new projects. A new slate of projects will be selected at the group's March 2015 meeting.

Contact: Tom Peters, Clear Roads Technical Advisory Committee representative, Research and Training Engineer, MnDOT Maintenance Operations, 651-366-3578, Tom.Peters@state.mn.us.

This Clear Roads project sought to provide recommendations for reducing or eliminating operator fatigue. Researchers augmented driving and actigraph data from four winter maintenance operators with a literature review and questionnaires collected from almost 1,500 winter maintenance operators and managers. (An actigraph

unit is a monitoring device that looks much like a wristwatch—though bulkier and heavier—that is used to assess the device wearer's sleep quantity and quality.)

Page 9 of the report (page 30 of the PDF) begins a discussion of equipment and fatigue management technology. The following summarizes the driver-centric assessments of fatigue addressed in this report. Back-office fatigue management technologies aimed at prevention are also addressed in the report but not highlighted below.

- *Fitness for duty.* These tests, which often measure hand-eye coordination and/or reaction time, assess a driver's cognitive ability before a shift begins.
- *In-vehicle monitoring.* These real-time, vehicle-based monitoring technologies assess such factors as physiological signals, psychomotor skills or lane position to predict or monitor fatigue. Systems can be single-channel or multichannel, with the latter combining two or more predictors of fatigue.
- *Crash avoidance systems.* These systems use steering input to detect changes in steering behavior that may indicate driver fatigue.

Study conclusions begin on page 99 of the PDF. A few highlights:

- Researchers noted that while literature concerning fatigue in winter maintenance drivers is sparse, much of the research relating to fatigue in commercial vehicle drivers can be applied to winter maintenance personnel.
- Research has indicated that whole-body vibrations and vehicle seat type may have an adverse impact on driver fatigue. This finding was borne out in the questionnaires winter maintenance operators and managers completed for this study.
- Traffic conditions and the complexity of work have been shown to contribute to the development of driver fatigue. However, light traffic or monotonous driving can also have a significant impact on the development of driver fatigue.
- Passive fatigue can be caused by an underload condition or by prolonged periods during which too few mental capacities are exercised. The underload condition typically occurs when the driver is very familiar with the environment, such as driving the same route with a relatively low traffic density.

Among the report's recommendations, which begin on page 105 of the PDF:

- Encourage the use of breaks or naps and body movement to reduce fatigue.
- Encourage winter maintenance operators to self-report fatigue.
- Increase vehicle maintenance or update equipment to reduce unnecessary truck vibrations and noise.
- Investigate winter emergency shift start/end times, including shift length. Research shows an increased risk of winter maintenance operator fatigue during circadian lows (between 2 and 6 a.m.). Starting or ending a shift during these times may be dangerous. This may also be the best time to encourage drivers to take a break.
- Involve winter maintenance operators in the decision-making process to develop an effective safety culture that minimizes operator fatigue.
- Increase personal interactions between managers and winter maintenance operators.
- Make use of free education and training resources available to assist safety managers in dealing with fatigue. (See **Training Resources** on page 5 of this report for information about two of the recommended training resources—CMV Driving Safety and the North American Fatigue Management Program.)

Snowplow Operation: Unique Issues in Fatigue Risk Management, Marlene Reimer, Adam Moscovitch, Ron Heslegrave and Matthew Kealey, undated.
http://www.ibrarian.net/navon/paper/SNOWPLOW_OPERATION__UNIQUE_ISSUES_IN_FATIGUE_RISK.pdf?paperid=11995175
This Canadian report examines the fatigue management processes of the six private contractors providing snow clearing services to Alberta, Canada, in conjunction with a review of relevant literature. Among the report's findings:

- Duration of driving is less important than time of day, time awake and previous sleep duration.

- A core component of most fatigue management programs is teaching people to recognize signs of fatigue and act on them. Research shows that people are moderately accurate in identifying when their performance is declining due to fatigue.

- Tolerance for erratic sleep schedules and sleep deprivation tends to decrease with age.

- Differences in hours of daylight between summer and winter affect mood and alertness.

- Vibration is known to generally be a fatigue-inducing factor. Mild motion has been shown to increase drowsiness, but the more intense vibration experienced in snow-clearing equipment has not been subjected to much empirical inquiry.

Techniques to Avert Fatigue

Rather than predicting or monitoring fatigue, the techniques described below are designed to improve a driver's ability to remain alert. These recently published articles address the use of strategically timed secondary tasks and the application of mechanical vibration to the right heel during long-distance drives to improve driving performance.

"A Strategically Timed Verbal Task Improves Performance and Neurophysiological Alertness During Fatiguing Drives," Paul Atchley, Mark Chan and Sabrina Gregersen, *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Vol. 56, Issue 3, pages 453-462, May 2014.
Citation at http://dx.doi.org/10.1177/0018720813500305
From the abstract: The objective of this study was to investigate if a verbal task can improve alertness and if performance changes are associated with changes in alertness as measured by an electroencephalogram (EEG). Previous research has shown that a secondary task can improve performance on a short, monotonous drive. The current work extends this by examining longer, fatiguing drives. The study also uses EEG to confirm that improved driving performance is concurrent with improved driver alertness. A 90-min, monotonous simulator drive was used to place drivers in a fatigued state. Four secondary tasks were used: no verbal task, continuous verbal task, late verbal task, and a passive radio task. When engaged in a secondary verbal task at the end of the drive, drivers showed improved lane-keeping performance and had improvements in neurophysiological measures of alertness. A strategically timed concurrent task can improve performance even for fatiguing drives. Secondary-task countermeasures may prove useful for enhancing driving performance across a range of driving conditions.

"Controlled Mechanical Vibration Applied to Driver's Right Heel to Sustain Alertness: Effects on Cardiovascular Behavior," Takehiro Yamakoshi, Kenta Matsumura and Peter Rolfe, *Transportation Research Part C: Emerging Technologies*, Vol. 38, pages 101-109, January 2014.
Citation at http://dx.doi.org//10.1016/j.trc.2013.10.009
From the abstract: Vehicle-related countermeasures to sustain driver's alertness might improve traffic safety. The purpose of this study was to investigate the effects of somatosensory 20 Hz mechanical vibration, applied to driver's right heel during prolonged, simulated, monotonous driving, on their cardiovascular hemodynamic behavior. In 12 healthy young male volunteers, during 90-min periods of simulated monotonous driving, the authors compared cardiovascular variables during application of 20 Hz mechanical vibration with 1.5 Hz as a control and with no vibration. The parameters recorded were indices of key cardiovascular hemodynamic phenomena, i.e., blood pressure as an indicator of stress, cardiac output, and total peripheral-vascular resistance.

The principal results were that all conditions increased the mean blood pressure, and elicited a vascular-dominant reaction pattern typically observed in monotonous driving tasks. However, mean blood pressure and total peripheral-vascular resistance during the monotonous task were significantly decreased in those receiving the 20 Hz vibration as compared with 1.5 Hz and with no vibration. The observed differences indicate the cardiovascular system being more relieved from monotonous driving stress with the 20 Hz vibration. The major conclusion is that applying 20 Hz mechanical vibration to the right heel during long-distance driving in non-sleepy drivers could facilitate more physiologically appropriate status for vehicle operation and could be a potential vehicular countermeasure technology.