Environmental Factors Causing Fatigue in Equipment Operators during Winter Operations

Task 1: Literature Review

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LITERATURE REVIEW

Research has shown that fatigue impairs and degrades driving performance by changing the behavior of the driver. A number of risk factors contribute to fatigue in commercial motor vehicle (CMV) drivers, including varying work schedules; unusual work shifts such as night driving; and long, monotonous driving conditions such as on interstates. The Large Truck Crash Causation Study conducted by the Federal Motor Carrier Safety Administration (FMCSA) reported that approximately 4 percent of truck crashes were primarily caused by the driver sleeping at the wheel and 13 percent involved driver fatigue as an associated factor (FMCSA, 2006). Also, fatigue was the primary factor in 31 percent of 182 truck crashes that were fatal to the driver and were investigated in 1990 by the National Transportation Safety Board (Knipling & Wang, 1994).

The terms “fatigue” and “drowsiness” are often used interchangeably in discussions of their impact on drivers. However, the causes of fatigue and drowsiness are fundamentally different, although their symptoms are generally the same. Fatigue is a physiological state that results in many symptoms, such as drowsiness and a reduction in task-related effort (Matthews et al., 2011). Drowsiness can be a result of fatigue, but it can also be due to other factors, such as a lull in the body’s natural circadian rhythm or poor sleep quantity or quality (Ferguson et al., 2012). Lal and Craig (2001) defined fatigue as the transitory period between wakefulness and sleep that, if not addressed, would lead to a state of sleep. Fatigue has been shown to adversely impact people in the following ways: changes in performance, impaired logical reasoning and decision-making, reduced situational awareness, and poor assessment of risk or failure to appreciate the consequences of certain actions (Bloomfield et al., 2009; Desmond & Hancock, 2001; Baulk et al., 2008; Lyznicki et al., 1998). Although fatigue and drowsiness are scientifically different, this paper will use the word “fatigue” hereafter to refer to a person’s propensity to feel sleepy, regardless of its genesis.

Studies use various methods to assess driver fatigue, but some of the most common methods are driving simulators, crash data from police accident reports (i.e., crash data and driving logs), and naturalistic driving studies. Hanowski et al. (2008) described a study that used naturalistic data in which unobtrusive data collection equipment installed in the vehicle took measures while the driver performed his or her normal driving tasks over a period of time. In contrast, driving simulators are generally seen as a safe and controlled way to study risky driving behaviors (Rossi et al., 2011).

In general, research has identified two types of fatigue in drivers: task-related (TR) and sleep-related (SL) fatigue. TR fatigue is associated with the tasks of driving, as well as the attention and focus required for the given driving conditions (May & Baldwin, 2009). For example, driving in a high-stress environment while completing work-related tasks may lead to TR fatigue. SR fatigue is related to time of day (circadian rhythms) and other sleep-related factors

(May & Baldwin, 2009), for example, a driver beginning to drive after an inadequate rest period or continuing to drive without a restorative period of sleep. Haworth et al. (1988) discuss fatigue as a neurological phenomenon stemming from levels of arousal, and an optimal level of arousal experienced by a driver minimizes fatigue. In this case, overarousal of the senses would be similar to active fatigue as presented by May and Baldwin (2009), as in sustained driving under demanding conditions. Underarousal of the senses is comparable to the passive TR fatigue as presented by May and Baldwin (2009), as in driving during monotonous and underdemanding conditions.

Figure 1 summarizes the two types of fatigue (SR and TR fatigue, which can be divided into active and passive). The current research has categorized several factors expected to contribute to each type of fatigue: the impact of trucks (i.e., the environment in cab and technologies existing in modern work vehicles), sleep deprivation, winter conditions (e.g., ice and snow on the roads), cold temperatures, traffic, scheduling and shift policies, and equipment (e.g., fatigue management technologies).

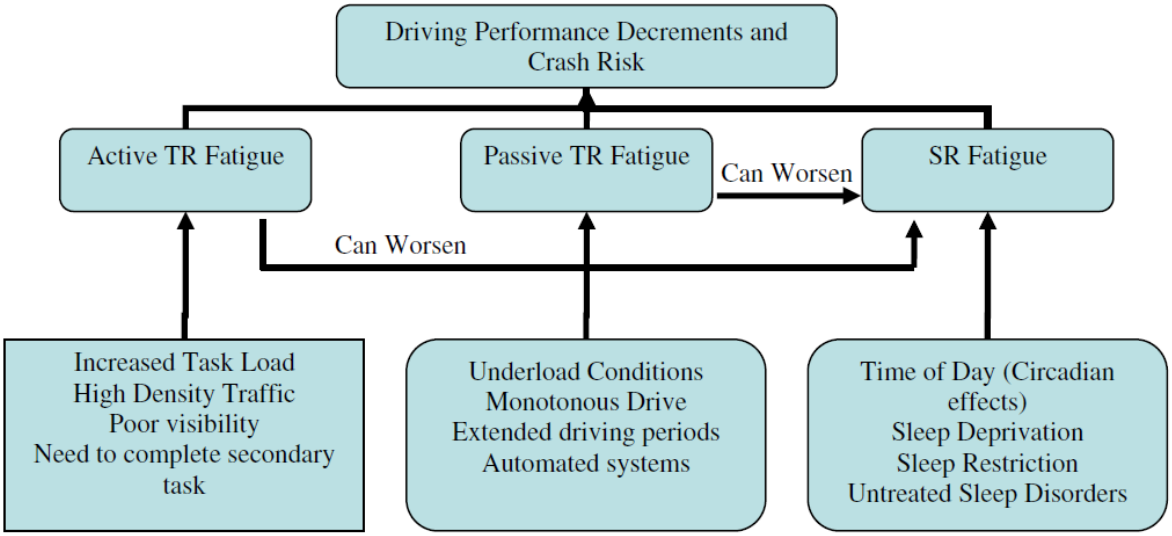

Figure 1. Two Types of Fatigue (May & Baldwin, 2009).

IMPACT OF TRUCKS

Noise, body posture, and vibration transferred from the truck to the driver are some of the factors that are controlled by the ergonomic design of the truck and cab, and they can directly impact driver stress, fatigue, and performance (Paschold & Mayton, 2011; Boggs & Ahmadian, 2007). Many modern CMVs are designed to mitigate fatiguing factors by using vibration isolation systems or by using materials that reduce noise coming from the outside environment. However, the mitigating impact of some components, such as foam seat cushions, decreases as they age.

Whole-body vibrations experienced by CMV drivers have been shown to directly and adversely impact driver fatigue (Paschold & Mayton, 2011). Vibrations of a certain frequency can cause muscle contractions, which lead to fatigue and reduced motor performance. Furthermore, particular body parts and internal organs vibrate at particular resonant frequencies, which amplify the vibrations and can cause discomfort or injury (Paschold & Mayton, 2011). Lower back fatigue caused by increased muscle contractions stimulated by whole-body vibrations may be exacerbated by the driver's seated position (Hansson et al., 1991).

Manufacturers of most modern CMVs have realized the importance designing and maintaining dampening systems to sustain a particular frequency of vibration within the truck cab. For example, research has shown that the first resonant frequency of the human spine occurs at approximately 5 Hz, which increases the axial load on the spine by a factor of 2 or 3 (Wilder et al., 1994). Thus, vibrations near 5 Hz should be avoided when designing the suspension. Generally, the design of these vibration isolation systems follows International Organization for Standardization (ISO) standards (ISO 2631-1:1997 *Mechanical shock and vibration: Evaluation of human exposure to whole-body vibration*) or American National Standards Institute (ANSI) standards (ANSI S3.18:2002 *Guide for the evaluation of human exposure to whole-body vibration*). These standards specify the range of vibrations that should be designed for, how to measure the vibrations, and how to evaluate the design of the vibration isolation systems.

In addition to vibration isolation systems, the design of the vehicle seat has been directly related to driver fatigue. In a study to determine the differences between traditional foam seat design and air-cushioned seats, Boggs and Ahmadian (2007) reported that drivers generally reported less fatigue over drive periods when using air-cushioned seats versus traditional foam seats. It is thought the reduction of fatigue may be due to increased resiliency of the air-cushioned seat (as opposed to foam, which becomes hard over time) and their adjustability.

Noise has also been identified as a factor that can lead to increased fatigue over time (Haworth et al., 1988). Some research has shown that noise can be a stimulant during monotonous tasks; however, fatigue that is induced by noise can be exacerbated in high-stress environments. The effect of noise has been described as a stressor, which, along with the cumulative effect of driving in a high-stress environment, induces higher levels of fatigue than either factor separately (Haworth et al., 1988). However, research has reported that effects that adversely impact driver performance have not been shown in the presence of noise levels less than 90 dB, emphasizing the impact of a controlled environment within CMV cabs (Haworth et al., 1988).

SLEEP DEPRIVATION

Sleep deprivation is a critical factor leading to driver fatigue and drowsiness. Sleep deprivation can be split into total sleep deprivation, a period of wakefulness that extends beyond a period of average daily wakefulness, and partial sleep deprivation (sleep restriction), a period in which some sleep is obtained but not enough to be considered restorative (Balkin, et al., 2000). The current report will refer to both cases as sleep deprivation. Crum and Morrow (2002) reported the most important factor influencing fatigue was whether the driver began the work week with less than adequate sleep (i.e., tired). Furthermore, scheduling policies that interfered with the driver's rest period (i.e., did not give adequate time to rest) were significant factors in driver fatigue.

Driver fatigue can be sub-categorized into SR and TR fatigue based on its causative factors (May & Baldwin, 2009). Some of the SR factors that contribute to fatigue are sleep deprivation, extended duration of wakefulness, and troughs in the circadian rhythm. It has been demonstrated that extended time awake, an inadequate amount of sleep, and time of day all increase fatigue among drivers (Ferguson et al., 2012). Horne and Reyner (2001) analyzed extensive crash data to separate vehicle crashes caused by SR fatigue from crashes caused by other factors. They also suggested policy implications resulting from previous studies. They concluded the only two significant deterrents of SR vehicle crashes were a nap or 150 to 200 mg of caffeine (Horne & Reyner, 2001). Activities such as turning the air conditioner on, briefly exercising, or rolling down the windows only provided momentary relief from feelings of sleepiness.

Numerous studies have shown the strong impact of the body's circadian rhythm on SR fatigue (Ferguson et al., 2012; May & Baldwin, 2009). A circadian rhythm acts as a biological clock and manifests as a lull in a person's energy level during certain points of time in a 24-hour period (Monk, 1991). The lull in the circadian rhythm corresponds to an increased propensity to sleep, and it generally occurs at two points throughout the day and night, typically the early morning and early afternoon. On average, the greatest propensity to sleep has been reported to occur between the hours of 02:00 to 06:00 (2:00 a.m. to 6:00 a.m.) and 14:00 to 16:00 (2:00 p.m. to 4:00 p.m.) (Horne & Reyner, 2001; Lyznicki et al., 1998).

Folkard (1997) reported clear temporal peaks in crash rates in the very early morning, which he referred to as "driving black times." The research indicated a clear relationship between an increase in crash rates and the corresponding time for an expected lull in the circadian rhythm; however, several other peaks in crashes were observed. These black times were signified by a reduction in performance across many sectors, including drivers and industrial workers. It was observed the black times could largely be described by sleep propensity, or the function describing the circadian rhythm, but circadian rhythms were not the only factor affecting the temporal distribution of the black times. Folkard concluded that time on task must be taken into account, along with time of day, to describe these temporal black times while driving.

A study conducted at the University of Minnesota's Center for Human Factors Systems Research and Design evaluated the effect of sleep deprivation on the driving habits of CMV drivers (Bloomfield et al., 2009). The study was conducted using a driving suimulator. The test subjects were allowed to consume caffeine and use tabocco products during the study in order to simulate more realistic driving habits, although the participants were required to exit the study building in order to smoke tobacco products. The study concluded that the steering behavior of CMV drivers is likely to be impared if the driver is awake from 8:00 or 9:00 a.m. to the time they attempt to drive 18 or more hours later (2:00 or 3:00 a.m.; Bloomfield et al., 2009).

The common factor found throughout the studies was a significant reduction in driving performance that corresponded with the expected lulls in the circadian rhythm. In general, it was found that the only reliable method of reducing the factors of fatigue related to drowsiness is to take a break from driving (Ferguson et al., 2012; May & Baldwin, 2009; Bloomfield et al., 2009). This rest break can be as short as 15 minutes or as long as 1 hour, without any activities related to driving being undertaken, to reduce the probability of fatigue-related incidents (Jovanis et al., 2011). Caffeine consumption preceding a rest period was reported to be the best combinationtion of techniques to combat fatigue.

TRAFFIC

High-traffic areas can contribute to driver fatigue by requiring sustained attention to the surrounding traffic while also completing driving tasks and communicating with central office personnel. Gimeno et al. (2006) presented a discussion of two types of task-based mental fatigue: passive fatigue and active fatigue. Passive fatigue can be caused by an underload condition, or prolonged periods in 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. Rossi et al. (2011) used a driving simulator to examine the impact of driving in a monotonous environment and concluded that the fatigue produced in the underload condition is a function of the time of day, driving environment, and duration of drive time.

Winter maintenance drivers may experience active fatigue as a result of the increased attention and multiple tasks required to operate a winter maintenance vehicle during a winter emergency. Active fatigue can be the result of overload, or relatively high driving demands are [e.g., high traffic density, unknown driving environment, or performance of multiple tasks while driving (Gimeno et al., 2006)]. Lui and Wu (2009) reported that fatigue from driving in a complex road environment had a significantly negative effect on driver behavior when compared to non-fatigued driving in a complex or monotonous road environment. These results indicated that fatigued drivers encountering significant or complex traffic tend to overestimate the distance to signs and have a significantly greater number of lane crossings than non-fatigued dirvers.

Some research has indicated that fatigue from driving in a low-demand environment or under low workload conditions may reduce performance more than fatigue from the overload condition (Desmond & Hancock, 2001). This is expected because drivers in low-demand conditions fail to fully mobilize their efforts (as opposed to high-demand conditions, in which effort is very high). However, the research only analyzed the impact of completing a task in environments with various demands placed on the operator and not the impact sustained demands had on the operator’s fatigue.

WINTER CONDITIONS AND COLD TEMPERATURES

It is expected that active fatigue can also be present during driving in winter conditions. For example, driving on ice- or snow-covered roads requires much more attention than driving on clear roads and contributes to the driver’s workload. Furthermore, high-demand driving conditions, such as driving in limited visibility (due to poor lighting and/or falling snow), can be expected in winter emergencies. These high-demand conditions lead to active fatigue, especially when combined with other fatigue-related factors such as vehicle vibration (Gimeno et al., 2006; May & Baldwin, 2009).

In addition to active fatigue from driving in winter conditions, exposure to cold temperatures has been connected to a decrease in cognitive functioning (Pilcher et al., 2002). Research has also shown that the longer a person is exposed to cold temperatures prior to performing a task, the more adversely the person was impacted by the cold temperatures, and exposure to cold temperatures for up to an hour prior to a task significantly impacts its performance (Pilcher et al., 2002). Research by Pilcher et al. (2002) indicated that the main decrements in performance during cold temperatures occurred in reasoning, memory, and learning. These results seem to suggest that winter maintenance drivers would experience a cumulative impact on fatigue when required to perform tasks outside of the truck (task-related fatigue) in cold temperatures. Short-duration exposure to cold air while performing a task (as may be the case when a driver must begin a shift before the truck cab has warmed up) also had a significant impact on performance (Pilcher et al., 2002). This research also discussed the negative impact of high heat on performance; thus, a conclusion can be drawn that there is an optimal middle temperature for activities requiring sustained performance.

Research has also shown that the combination of sleep deprivation and exposure to cold temperatures significantly exacerbates the reduction of an individual’s attention capacity and working memory (Spitznagel, et al., 2009). Although the impacts of sleep deprivation and cold temperatures impact driver performance and levels of fatigue, the combination of the two is expected to accelerate a decrease in performance. However, the research conducted on the combination of sleep deprivation and cold temperatures was conducted only on young, relatively healthy males (Spitznagel, et al., 2009), limiting the generalization of the results to other populations of drivers.

SCHEDULING AND SHIFT POLICIES

Much research has tried to quantify the impact of scheduling and shift policies on the performance and safety of CMV drivers. For example, much research has been conducted to evaluate the impact of federal Hours-of-Service (HOS) legislation. However, some of the research has produced conflicting results that may lead to confusion about the cumulative impact of driving and rest periods on driver fatigue. It is generally recognized that time of day has an impact on driver fatigue: the frequency of fatigue-related traffic incidents increases between midnight and 6:00 a.m. (Desmond & Hancock, 2001).

Hanowski et al. (2008) used data from a naturalistic driving study to examine critical incidents as a function of driving hour during 11 continuous hours of driving. The research followed 98 drivers for an average of 12.38 weeks, resulting in more than 2.3 million miles of driving data (Hanowski et al., 2008). The results of the research showed a spike in critical driving incidents during the first driving hour, and no other hours were statistically significant. The results indicated that time on task is a poor indicator of crashes or other traffic incidents for driving hours 1 through 11. The research presented three possible explanations for the spike in the first hour of driving: (1) sleep inertia, (2) road type and/or traffic density, and (3) time-of-day effects. Sleep inertia describes the time the body requires to become fully alert after awakening. The time-of-day effects are attributed to the body's circadian rhythm and traffic density.

Jovanis et al. (2011) studied the increase in crash proabability with increased drive time of CMV drivers. The authors studied the driving logs of 1,564 drivers, a number of whom had reported crashes. The authors found a significantly greater probability of crashes in the 11th hour of driving for less-than-truckload drivers (e.g., drivers who move loads for multiple firms on the same truck), with increasing probabilities of crashes beginning in the 6th driving hour and increasing with driving time (Jovanis et al., 2011). The authors reported that taking breaks from driving at any point during the drive time significantly reduced the probability of a crash. The authors also reported that truckload drivers (e.g., drivers who carry loads for one firm between the firm's docks) experienced an increased crash probability. However, the authors warned against drawing too many conclusions from the limited data on the impact of the 34-hour restart period.

Blanco et al. (2011) investigated the impact of non-driving activities (i.e., loading and unloading) on driver performance. The research analyzed data from a naturalistic driving study and found that, on average, the drivers spent 66 percent of the time on shift driving, 23 percent on non-driving work, and 11 percent resting (Blanco, et al., 2011). The results of the study indicated the increase in fatigue was a function of time on task and the non-driving activites of the CMV driver. In other words, CMV drivers may be able to drive safely for long periods of time; however, if they are required to load and unload, fatigue related to time on task was shown to increase.

McCartt et al. (2008) evaluated the impact of the 2004 changes in HOS legislation on drivers' schedules and reported fatigue. The legislation changed many of the driving limits, as well as the off-time requirements (Table 1). The legislation also enacted the 34-hour restart period, requiring that drivers could restart the official work week only after 34 consective hours off. The research found that drivers reported significantly more driving hours after the rules changed. Drivers who reported rules violations to the researchers were also significantly more likely to report having driven while drowsy within the past week. Furthermore, driver fatigue was reported to be higher after the new rules went into place.

Table 1. 2004 Rules Changes (Adapted from McCartt et al., 2008).

	Old Rule	New Rule
Daily Limit	10 hours driving after 8 hours off duty; up to 16 hours of driving per 24-hour period	11 hours driving after 10 hours off duty; up to 14 hours of driving per 24-hour period
Daily Off-Duty	After driving 10 hours or working 15 hours, driving is not allowed again until after taking 8 hours off; may log off duty for breaks to extend 15-hour on-duty shift	After driving 11 hours or if 14 hours have passed since driver started duty, driving is not allowed again until after taking 10 hours off duty; may not log off duty during 14-hour on-duty shift
Sleeper Berth Exception	May split required 8 hours off duty into two periods in a sleeper berth (period must be 2 hours or longer)	May split required 10 hours off duty into two periods in a sleeper berth (period must be 2 hours or more); revised effective October 1, 2005, so that at least 8 consecutive hours must be taken in a sleeper berth, plus 2 consecutive hours either in sleeper berth, off duty, or any combination of the two
Restart Period	Not applicable	May restart official work week after 34 consecutive hours off
Weekly Limits	60 hours in 7 days or 70 hours in 8 days	60 hours in 7 days or 70 hours in 8 days, but restart provision allows up to 77 hours in 7 days, 88 hours in 8 days
Work-Hour Limits	No daily work-hour limits; no weekly work-hour limits	
Monitoring for Compliance	Handwritten logbooks; voluntary use of automated recorders permitted	

When scheduling work periods, it is important to recognize that sleep quantity and quality impact the fatigue experienced by drivers. Research has shown that accumulated sleep debt has an impact on the feeling of daytime sleepiness (Dinges, et al., 1997). It is generally accepted that most people need approximatley 8 hours of sleep to feel well rested (Pa Van Dongen et al., 2003). The highest quality sleep happens when sleep is coordinated with the circadian clock; daytime sleep is often shorter and more disrupted than nighttime sleep. Obtaining a full night's sleep can sometimes be a challenge for people working irregular or unpredictable schedules. Research has shown that 8 continuous sleep hours after a wakeful period of 26 hours should be adequate to return normal motor-skills functioning (Baulk et al., 2008).

Morrow and Crum (2004) analyzed survey data from 116 trucking firms and found that a strong safety culture has the potential to significantly reduce the occurrence of driving while fatigued. The safety culture could range from limiting the non-driving factors that could contribute to fatigue (i.e., during the loading and unloading process) to dissuading dispatchers from trying to convince drivers to continue driving after they report drowsiness (Morrow & Crum, 2004). A positive safety culture could also include programs that disincentivize driving after reporting fatigue. Communications with dispatchers or central office personnel were found to be critical aspects of the safety culture when trying to manage the amount of time a driver works after reporting fatigue.

The research often notes that economic pressures directly related to driving incentivize CMV drivers to drive fatigued (Lyznicki et al., 1998). CMV drivers are generally paid by the mileage driven, so an increase in drive time has a direct economic benefit for most CMV drivers. Crum and Morrow (2002) presented a truck driver fatigue model to explain the factors that contribute to driver fatigue. Some notable factors were various economic pressures (Crum & Morrow, 2002). However, most winter maintenance personnel are employed by a state department of transportation, so the overhwleming majority of these employees are paid by the hour.

EQUIPMENT AND FATIGUE MANAGEMENT TECHNOLOGIES

Fatigue management technologies are state-of-the-art innovations for preventing, identifying, alerting, and reducing driver fatigue and fatigue-related driving errors. These technologies generally focus on three types of measures: non-driver measures, such as fatigue modeling; driver physiological measures and psychomotor skills, such as eye tracking to detect fatigue; and vehicle kinematics or driver input, such as measuring the amount of lane drift (Balkin et al., 2011; Ji et al., 2004). There are two types of fatigue management technologies, back-office and driver, which are further subdivided into in-vehicle and out-of-vehicle technologies.

Fitness for Duty

A fitness-for-duty test involves technologies to measure a driver's cognitive ability before a driver begins a shift (Balkin et al., 2011). Tests of cognitive functions use an objective process and typically measure hand-eye coordination and/or reaction time, and they can be used as pre-drive monitoring. These relatively short, non-invasive tests are used as a predictor to determine whether a driver may be too fatigued for the task at hand (Horberry et al., 2001).

Technologies that measure psychomotor skills present some limitations. Technology used prior to driving must be administered by personnel in the back office, does not take into account possible onset of fatigue at a later time during the driving shift, and may be vulnerable to drivers beating the system (i.e., engaging in behavior just prior to testing that temporarily mitigates the symptoms of fatigue). Technologies that measure a driver's psychomotor skills while driving create an additional task for the driver to perform, increasing the possibility of driver inattention.

Actigraphy is another fatigue measure using physiological concepts (Dinges et al., 2005; Baulk et al., 2008). This concept uses predictive sleep algorithms to determine the driver's sleep quantity and quality, along with rest and activity patterns. Some devices may also incorporate circadian rhythm analyses into the algorithm. Actigraphy devices provide a general indicator of sleep variability. These devices are typically wrist-worn watches and may include a light sensor, ambient temperature detection, and off-wrist detection. It is important to note that actigraphy devices are predictive technologies that do not account for individual differences and require the driver to wear the device. Furthermore, actigraphy devices do not provide the driver real-time alerts or data.

Back-Office Fatigue Management Technologies

Back-office fatigue management technologies are aimed at prevention. They include in-vehicle systems designed to monitor the driver and roadway with video and kinematic sensors (Horberry et al., 2001). Some of these systems also record data from the vehicle network, such as speed, braking, and GPS location. Crossing certain thresholds, such as sufficiently hard braking, triggers event markers in the video and data recording. The video and data are collected, transferred (generally by vehicle telemetry or wireless internet), and reviewed and analyzed. This process can be handled either by a third party or within the fleet, depending on the system employed. This allows risky driving behavior to be flagged for review by the safety manager, who can coach the driver to reduce risky driving behavior in the future. Behavior-based coaching systems are for overall driving behavior, not just fatigue management (Hickman et al., 2007). Mitigating distracted driving and increasing fuel economy are just two of the other uses of this type of system.

In-Vehicle Monitoring

In-vehicle driver fatigue management technologies are designed to identify and alert the driver to impending fatigue to reduce risky driving behaviors, performance degradation, and driver errors. Real-time driver monitoring occurs in-vehicle and uses physiological measures, psychomotor skills, vehicle kinematics, or driver input (Fletcher et al., 2005). Real-time driver monitoring is seen as the last stop-gap countermeasure that warns the driver before potential risky driving behavior or a crash could occur.

Over the past few decades, much research has studied the use of eye measures when determining fatigue. Perclos is the percent closure of the driver’s eyelids and is typically considered one of the more effective in-vehicle measurements of driver drowsiness (Ji et al., 2004). Amplitude velocity ratio is a measure of how fast and how far the eyelid opens after closure and is another eye measurement that can be used to measure fatigue. Physiological concepts present several potential limitations: systems that use eye measures can produce false alarms for glances to mirrors and in-cab devices, the sensitivity of camera and infrared varies under different lighting conditions, and there is driver resistance to systems that require them to wear glasses.

In-vehicle fatigue management technologies are either single- or multi-channel systems. Single-channel systems, such as lane departure warning systems, rely on one predictor of fatigue. Single-channel systems also have the potential for intermittent data loss. For example, snow-covered roads could render a lane departure warning system ineffective. Multi-channel systems combine two or more predictors of fatigue. An example of a multi-channel system would be a lane departure warning system with eye tracking using Perclos algorithms. This creates a more robust system for monitoring driver fatigue by compensating for the weaknesses of each predictor. It is expected that a multi-channel system could be created with currently available single-channel systems.

Crash Avoidance Systems

Crash avoidance systems are designed to warn a driver of driving behaviors that may lead to a crash, and they have applications in fatigue management. Vehicle kinematics and driver-input fatigue management technology concepts use lane tracking or steering input as the driver performance measure (Dinges et al., 2005). Lane tracking uses computer-based algorithms in conjunction with a camera, machine vision, and vehicle state to monitor lane position. These systems warn the driver, usually with an auditory alert, when he or she is deviating from the travel lane. Lane departure warning systems tend to improve overall attention and performance even when the driver is not fatigued (Dinges et al., 2005).

Fatigue management technology systems using steering input as the performance measure use a computer sensor to detect the actual amount of steering input and changes in steering behavior, such as rapid lateral movements of the steering wheel (also known as drift and jerk steering). When programmed thresholds are met, the system warns the driver.

FATIGUE SURVEYS

Many studies use fatigue surveys that elicit responses directly from drivers following a driving session or study. The structure of these surveys is critical for the way the information being gathered can be used and determining which assumption can or must be made. Surveys are also a useful way to reveal factors that are important to a study but may not have been identified otherwise. This section discusses some of the components of the surveys used in various driver fatigue studies and the sample populations surveyed.

Adams-Guppy and Guppy (2003) present the results of an investigation on driver fatigue using driver questionnaires in large multi-national corporations. The questionnaire was sent to managers and drivers and contained the following sections: reported frequency of fatigue problems (e.g., *How often do you drive while tired?*), reported crash and near miss experience, driver biography and driving history, work features (e.g., hours worked and miles driven per week), driver behavior and perceptions related to taking breaks, satisfaction and involvement with work environment, and restraint in alcohol consumption (Adams-Guppy & Guppy, 2003). One issue that was discussed was bias in the questionnaire responses. It is expected that many drivers with poor driving histories would not complete the questionnaire, resulting in questionable validity in some of the conclusions (Adams-Guppy & Guppy, 2003). However, even with the expected bias, it is thought the information gleaned from the questionnaires was adequate for drawing out the relationships among the study’s variables. The results showed a relationship between self-reported fatigued driving and self-reported near misses and crashes. No relationship was found between fatigued driving and age or years of driving experience. A relationship was shown to exist between an increased frequency of driving while tired and an increasing disagreement that breaks were encouraged by their employers. The results also indicated a slight increase in driving while fatigued when the driver began a shift prior to 7:00 a.m. (Adams-Guppy & Guppy, 2003). Finally, an increase in fatigued driving was found in drivers who did not limit the amount of alcohol they consumed the night prior to driving.

Gander et al. (2006) reported the results of a three-page questionnaire designed to assess driver fatigue in truck crashes. The questionnaire was designed to collect driver age and gender, sleep habits and sleepiness (i.e., information about feeling refreshed after sleep as well as neck circumference data), sleep and duty history for 72 hours prior to the crash, how long it had been since the driver had two good successive nights of sleep (for sleep recovery opportunity), and information about the crash (Gander et al., 2006). The research revealed that the questionnaire-based method identified fatigue-induced crashes at a significantly higher rate than the standard method, which involved the attending police officer simply checking a box for fatigue at the crash investigation. However, one drawback to the surveys was the retrospective and subjective nature of gathering the information a significant amount of time after the crash occurred (Gander et al., 2006). The results showed the three measures that contributed most to the differences between fatigued and non-fatigued crashes were the duration of the most recent sleep, number of hours slept in the 24-hour period prior to the crash, and whether the driver had a split-sleep pattern the in 24 hours prior to the crash. The vast majority of the crashes (86.3 percent) occurred on roads familiar to the driver.

CONCLUSIONS

Although the research concerning fatigue in winter maintenance drivers is sparse, much of the research relating fatigue to CMV drivers can be applied to winter maintenance personnel. For example, inconsistent and varying schedules, which have been shown to contribute to fatigue in CMV drivers, are inherent in the job of winter maintenance drivers due to the unpredictability of winter storms. Also, winter maintenance drivers are generally required to work long shifts while performing many activities in addition to driving (e.g., communicating with central office personnel or monitoring the application of de-icing agents) during winter emergencies (during which they are not subject to HOS regulations), which can lead to the onset of task-related active fatigue. Below are a number of conclusions and recommendations, based on the literature review, that should be applied to reduce the level of fatigue in winter maintenance drivers.

- Research has shown that driving in high-stress environments while completing multiple tasks leads to the onset of fatigue. Those who schedule winter maintenance drivers' work should consider the job's driving location (e.g., rural area with minimal traffic versus urban area with high traffic density) as well as the number of required non-driving activities.
- Scheduling and shift policies should consider the onset of SR fatigue, which has been shown to occur around the same times as the lulls in the circadian rhythm: 02:00 to 06:00

(2:00 a.m. to 6:00 a.m.) and 14:00 to 16:00 (2:00 p.m. to 4:00 p.m.). In this case, activities to mitigate the onset of SR fatigue, such as caffeine consumption preceding a rest period, should be built into the drivers' schedules.

- A relationship was found between the drivers' perception of management's attitude toward rest and fatigued driving, with an increase in reported fatigued driving when drivers percieved an environment that marginalized breaks. An important step to mitigating fatigued driving is to ensure that managmenet takes a proactive approach to promoting breaks and rest periods.
- Drivers' rest periods preceding the shift should be taken into account when scheduling winter maintenance drivers. Some research showed that the most significant factor leading to the onset of fatigue was beginning the work week tired. Furthermore, the research showed that sleep schedules that do not correspond to the circadian rhythm do not tend to provide adequate amounts of rest. Therefore, whether the driver was required to work a night shift just prior to being scheduled should be accounted for before requiring another night shift of the same driver.
- The ergonomic design of the cab of the truck is important to minimizing fatigue. Thus, care should be taken to ensure that components used to reduce fatigue, such those that reduce outside noise and minimize whole-body vibrations, are kept in a good state of repair.
- The combination of inadequate sleep with cold temperature exacerbates the onset of fatigue, particularly when work is performed in cold weather prior to completing other tasks. Warming the cab of the truck prior to the beginning of a driver's shift ensures that the driver does not have to perform a number of tasks in cold temperature and mitigates some factors of the onset of fatigue.
- Non-driving activities (i.e., loading the truck, etc.) prior to driving impact the level of fatigue and should be taken into account when determining the length of the driver's scheduled work period. For example, a driver who must conduct some physically demanding activity prior to driving should have less required drive time than a driver whose only responsibility is driving, with all other factors the same.
- Finally, various fatigue management technologies measure driver behaviors and vehicle dynamics to help detect the onset of fatigue as well as prevent fatigued driving by detecting fatigue before a shift begins. This literature review outlined and categorized a number of fatigue management technologies that work to prevent, identify, alert, and reduce driver fatigue and fatigue-related driving errors. Any one of these fatigue management technologies or a combination should be implemented into a fatigue management program to help mitigate fatigue in winter maintenance drivers.

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