U.S. Department of Transportation

Federal Railroad Administration

Data Analysis for Maintenance-of-Way Worker Fatigue

Office of Research, Development and Technology
Washington, DC 20590

DOT/FRA/ORD-19/02

Final Report
March 2019

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 2019	Technical Report - March 7, 2018

4. TITLE AND SUBTITLE Data Analysis for Maintenance-of-Way Worker Fatigue	5. FUNDING NUMBERS N/A
6. AUTHOR(S) Kumagai, Jason K. and Harnett, Mike	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SIX Safety Systems 250031 Mountain View Trail Calgary, AB T3Z 3S3 Canada	8. PERFORMING ORGANIZATION REPORT NUMBER N/A
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Office of Research, Development and Technology Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-19/02
11. SUPPLEMENTARY NOTES COR: Rachel Grice	
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA website.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report examines the relationship between accidents and incidents amongst U.S. maintenance-of-way (MOW) employees and their corresponding work schedules to determine if fatigue-related factors potentially contributed to the events. Ten U.S. railroads participated in the study by providing MOW data. Study methodology consisted of using a biomathematical fatigue model to review work schedules to determine if they exceeded thresholds of acceptability on 12 factors that are known to be related to impaired performance due to fatigue. Participating railroads provided 10-day schedules to facilitate modeling of fatigue prior to the accident or incident. Exceeding the fatigue risk threshold on any of the 12 factors indicates elevated risk due to fatigue accumulation and subsequent impairment of performance. Results indicate that portions of the work schedules exceeded fatigue risk threshold levels for almost all 12 factors measured and in some cases, there were multiple factors that contributed to exceeding the fatigue risk threshold. This understanding can inform efforts to optimize MOW worker schedules to reduce fatigue and related human performance errors. The results may also support changes to safety standards regarding regulations for MOW work/rest periods to be consistent with other railroad employee work/rest regulations.

14. SUBJECT TERMS Fatigue, work schedule, maintenance-of-way, sleep pattern, alertness, shiftwork, hours of service, biomathematical fatigue model	15. NUMBER OF PAGES 39
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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Executive Summary

This study examined the relationship between accidents and incidents amongst U.S. maintenance-of-way (MOW) employees and their corresponding work schedules, and identified specific fatigue characteristics that were present within the employees' schedules at the time of the events. The research was conducted in 2017 by Six Safety Systems and sponsored by the Federal Railroad Administration (FRA).

MOW workers are responsible for maintaining railroad infrastructure at all times of the day. This comes with unique physiological challenges on the workforce that can impact fatigue, compromise alertness, and impair performance. The consequences are operational, societal, and personal. MOW workers are often required to perform highly physical work, out of doors, and with irregular schedules that are not covered by Hours of Service laws or regulations.[1 2] Shift work, night work, and irregular schedules are recognized for disrupting circadian rhythms and the natural sleep-wake cycle necessary for physical and cognitive recuperation. As a result, MOW workers are vulnerable to fatigue-related human performance errors.

Ten U.S. railroads participated in the study by providing MOW schedule data. The schedule data was analyzed with a biomathematical fatigue model, Fatigue Audit InterDyne™ (FAID®) Quantum. The methodology consisted of using the FAID biomathematical fatigue model to review 12 fatigue factors associated with work schedules to determine if they exceeded specific risk thresholds. Schedules of the 10 days prior to each accident/incident were requested from the railroads to ensure at least 1 week of time could be considered in the models. Exceeding the fatigue threshold on any of the 12 variables indicates an elevated risk of a human-factor accident due to fatigue accumulation and subsequent impairment of performance.

A control group was selected from the provided schedules to act as a benchmark for comparison. A total of 135 10-day schedules were generated for the control group. Since the control schedules were selected from MOW workers who had had an accident in close time proximity (within 4 months), the control schedules may have been more predisposed to high fatigue risk factors than other MOW workers.

FRA has established a fatigue threshold, which is the fatigue level at which the risk of a human-factor accident is greater than chance. A FAID Score benchmark figure equal to a "72/20 threshold" was used as the Fatigue Score Tolerance Level (FTL) in this study. This means that the fatigue threshold is exceeded if an employee's [FAID] score is more than 72 for 20 percent, or more of the employee's time on duty. Additional factors that have been characterized to influence human alertness and impaired performance due to fatigue were also measured.

Results indicated that portions of the work schedules exceeded fatigue threshold levels for almost all 12 factors measured. It is recommended that railroads conduct regular analysis of their MOW schedules to identify and monitor the degree to which they exceed fatigue risk thresholds. Based on the data analysis, recommendations to address fatigue risk are provided below, related to the 12 factors:

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[1] Chapter 211 – Hours of Service.

[2] 49 CFR Part 228, Subpart F

i. Time of day (circadian phase) of the events: Recognize the increased likelihood of accidents and incidents between 1200–1600 and 2400–0400.

ii. Compliance of schedules with FRA-established fatigue threshold (FAID compliance): Identify and address schedules for which FAID compliance is less than 80% (i.e., greater than 80% of FAID Scores of an individual's schedule should be below the FTL of 72).

iii. Peak fatigue level (FAID Score) within the 10-day schedule: Identify and address aspects of schedules that cause peak FAID Scores that exceed the FTL of 72.

iv. Peak fatigue level (FAID Score) prior to event: Identify and address aspects of schedules that cause peak FAID Scores that exceed the FTL of 72.

v. Level of fatigue (FAID Score) at the time of the event: Identify and address aspects of schedules that cause peak FAID Scores that exceed the FTL of 72.

vi. Total hours worked: Identify and address schedules that exceed 90 hours of total work over a 10-day period.

vii. Long work shifts: Identify and address schedules that exceed 16 hours of continuous work.

viii. Total hours worked at night: Identify and address schedules that exceed 48 hours of night work over a 10-day period.

ix. Short sleep within the 10-day schedule: Identify and address schedules for which the predicted/modelled hours of sleep is less than 5 hours.

x. Sleep obtained prior to event: Identify and address schedules for which the predicted/modelled hours of sleep is less than 5 hours.

xi. Long breaks: Identify and address schedules that do not provide at least one long break (a period of two-night sleep opportunities with a non-working period in between) over a 10-day period.

xii. Short breaks: Identify and address schedules that have at least one short break (less than 8 hours off-duty) over a 10-day period.

The results of this study can inform efforts to optimize MOW worker schedules to reduce fatigue and related human performance errors. Particular efforts should be made by railroads to reduce long work hours and ensure sufficient turnaround times, thus eliminating what is referred to as short breaks. The results may also support changes to regulations for MOW work/rest periods to be consistent with other railroad employee work/rest regulations. This report concludes with recommendations on future research and the promotion of fatigue management systems.

1. Introduction

This report describes the results of an analysis of U.S. maintenance-of-way (MOW) employee accidents and incidents along with corresponding schedule data to determine if there were fatigue-related factors potentially contributing to the events. A biomathematical fatigue model (BFM) was used to review the schedules of MOW workers. The research was conducted in 2017.

1.1 Background

MOW workers are responsible for maintaining railroad infrastructure at all times of the day as around the clock operations are necessary to meet the demands of an industrialized global economy, but it comes with unique physiological challenges on the workforce that can impact fatigue, compromise alertness, and impair performance. The consequences are operational, societal, and personal. MOW workers are often required to perform highly physical work, out of doors, and with irregular schedules, which are not covered by lawful restrictions in rest periods (Sussman, D., & Coplen, M., 2000). Shift work, night work and irregular schedules are recognized for disrupting circadian rhythms and the natural sleep-wake cycle necessary for physical and cognitive recuperation. As a result, MOW workers are vulnerable to fatigue-related human performance errors.

In 2001, a study was conducted to investigate the fatigue issues of MOW workers (Gertler, J., & Viale, A., 2006). The survey-based study found that MOW workers are a predominantly healthy middle-aged male population. They work either production (construction) or non-production (maintenance) jobs and focus on either track or bridge and building infrastructure. Most non-production jobs have a 5-day work week, and nearly half of production jobs work a 4-day week. An additional 20 percent of production workers work for 8 days followed by 6 days off. Overall, 24 percent of MOW workers traveled on their own time to an out-of-town worksite during the study's 2-week period. Several work schedule characteristics, including time without a break, total hours worked, weeknight emergency calls, and commute time, were related to daytime alertness, but their relationship was statistically weak.

A high prevalence of human factors-related safety accidents and incidents was found among MOW workers. The presence of fatigue can increase the likelihood of human factors-caused railroad accidents or incidents occurring (Van Dongen, H. P. A., Maislin, G., Mullington, J. M., & Dinges, D. F., 2003) (Gertler, J., Difiore, A., & Raslear, T., 2013).

1.2 Objectives

The objective of this study was to analyze U.S. MOW employee accidents and incidents along with corresponding schedule data to determine if there are a fatigue-related factors related to the resulting accidents and incidents and subsequently, provide direction on a path forward.

Understanding the relationship between fatigue and risk for accidents or incidents can inform efforts to optimize MOW worker schedules to reduce fatigue and related human performance errors. The results may also support changes to safety standards regarding regulations for MOW work/rest periods to be consistent with other railroad employee work/rest regulations.

1.3 Scope

This study involved railroad MOW workers working in the United States. It was designed to characterize these workers as an industry group. The study did not attempt to characterize MOW workers employed by specific railroads.

1.4 Organization of the Report

Section 2 describes the overall study design, the BFM analysis of the schedules, and the findings. Section 3 contains the results. Section 4 includes conclusions and recommendations.

2. Study Design

2.1 Railroad Participation

Ten passenger railroads provided summary information for 818 MOW Federal Railroad Administration (FRA) reportable accidents and/or incidents (rules set forth at Title 49 Code of Federal Regulations (CFR) Section 225.19(d)). The requested data was to include, at least, the accident date/time, and the worker's schedule for at least 10 days preceding the incident/accident. An "accident" was considered to be an event that resulted in damage to rolling stock or roadway maintenance equipment and/or an employee casualty (injury or fatality). An "incident" was considered to be a non-accident involving a railroad rule violation (e.g., roadway maintenance equipment fouling a live track). FRA requested 10-day schedules from the railroads. This provided at least 7 days of activity prior to the accident or incident to help ensure the potential influence of any work performed prior to the accident or incident was considered in the analysis. Only data that included complete 10-day schedule information, consisting of 10 continuous calendar days of hours worked, could be used in the analysis.

2.1.1 Data Errors

Data errors were found in 33% of the worker schedules provided making that data unusable in the analysis. Errors included information provided for the incorrect worker, shifts lacking a specific start and/or end time, schedule data that did not include the 10-days prior to the event, or no schedules provided for events.

In some instances, the work shift on which the event occurred was not provided. Instead, the 10-days worked prior to that shift were provided. It is possible that the shift could not be clocked as complete or closed-out as a result of being involved in the specific accident or incident. To include this data (54 events or 9.8% of usable data) in the analysis, the shift that was worked prior to the date of the event was used to represent the final shift.

Once data errors were accounted for, a total of 463 accidents and 87 incidents from 8 passenger railroads had sufficient detail to be included in the analysis. All events occurred between 2013 and 2017. Many of the events (370) occurred in 2015, given that the original request for recent events was made in 2016. In the data used in the analysis, it was noted that some of the workers appeared to work an extremely long number of hours at once, or a number of consecutive shifts that added up to a long on-duty time. This could possibly be explained by a missed punch-out. Occasionally this anomaly corresponded to the incident and a plausible explanation could be that the punch-out was missed because the worker was injured and left the job unexpectedly. In these cases, the time of the incident was used to demark the end of the shift.

2.1.2 Control Data

A control group was selected from the provided schedules to act as a benchmark for comparison. Only one of the participating railways provided sufficient schedule data that could be used for the control group. These schedules were collected from the same participants that had experienced an FRA reportable accident. The control data was captured by randomly selecting a 10-day time period prior to the event if it did not overlap the accident date or the 10 days prior.

A total of 135 10-day schedules were generated for the control group. As the control schedules were selected from workers who had an accident in close time proximity (within 4 months), the control schedules may have been more predisposed to high fatigue risk factors than other MOW workers. However, schedule data from MOW workers that had not experienced an FRA reportable event were not available for this study.

2.1.3 Coding

Not all the summary information provided by the participating railroads contained detailed descriptions of the events and information to supplement the schedule information. Incomplete and inconsistent information prevented comparison between events on factors such as the type of injury, body part injured, lost time, etc. Furthermore, descriptions did not provide sufficient information to make confident judgements on the potential contribution of human error such as slips in attention or lapses in memory. Demographic information was not provided for all events so comparisons across factors such as age, gender, years of experience and geographic location were not possible. Due to these limitations, analysis only included schedule data (i.e., work time and non-work time).

2.2 Biomathematical Fatigue Modeling

The schedule data was analyzed with a biomathematical fatigue model, Fatigue Audit InterDyne™ (FAID®) Quantum. FAID was developed by InterDynamics and uses algorithms and formulas based on the results of research undertaken at the University of South Australia's Centre for Sleep Research (Roach, G., Fletcher, A., & Dawson, D., 2004) FAID is a tool for the analysis of planned or actual hours of work from which indicative fatigue levels for individuals or groups can be determined. The model is based on biological determinants of fatigue including: time of day of work and breaks; duration of work and breaks; work history in the preceding seven days, and biological limits on recovery sleep. The model is structured upon a probabilistic scoring method with weighting scores for each hour of a day for both work and rest.

FAID results identify times when workers encounter elevated risk of fatigue in their schedules, and can then be used to help manage the risks associated with fatigue. FAID has been validated and calibrated using accident data from freight railroads (Tabak, B., & Raslear, T. G., 2010). FRA further determined that FAID was valid for use in evaluating fatigue levels in passenger railroad schedules. With each schedule, a FAID Score is provided, indicating different levels of fatigue exposure for different work hours. The higher the FAID Score, the higher the fatigue exposure. Multiple validation studies (Fletcher, A., 1999) (Fletcher, A., & Dawson, D., 2001) (Fletcher, A., Lamond, N., Van den Heuvel, C., & Dawson, D., 2003) (Stewart, S., & Abboud, R., 2005) (Dorrian, J., Hussey, F., & Dawson, D., 2007) have shown that higher FAID Scores indicate lower likelihood of sleep opportunity or recovery, higher probability of impairment of objective vigilance and performance, and greater subjective sleepiness and tiredness associated with hours of work. Scores between 80 and 100 are comparable to the level of fatigue-related impairment after 21–24 hours of continuous sleep deprivation (Dawson, D., & Reid, K., 1997). Multiple studies have shown that performance impairment at such a level of sleep deprivation is comparable to that experienced at blood alcohol concentrations of over 0.05% or 0.08% (Fletcher, A., Lamond, N., Van den Heuvel, C., & Dawson, D., 2003) (Gertler, J., Difiore, A., & Raslear, T., 2013). FRA's calibration of FAID indicated that FAID Scores above 80 indicate a severe level of fatigue, and that FAID Scores between 70 and 80 indicate extreme fatigue.

However, FRA report findings in regard to FAID Score intervals and safety outcomes advise: "A FAID Score of less than 80 does not mean necessarily that a person is not impaired by fatigue, or that a work schedule is appropriate from a fatigue risk management perspective" (Tabak, B., & Raslear, T. G., 2010).

FRA has established a fatigue threshold, called a FAID Score Tolerance Level (FTL), which is the fatigue level at which the risk of a human factors accident is greater than chance. A FAID Score benchmark figure equal to a "72/20 threshold" has been established for the rail industry and was used as the FTL in this study (see 49 CFR, Subtitle B, Chapter II, Part 228, Subpart F, Section 228.407(c)(2)). This means that the fatigue threshold is exceeded if an employee's [FAID] score is more than 72 for 20 percent or more of the employee's time on duty.

3. Results

This section describes the analysis of data for factors that have been recognized to influence human alertness and have been related to impaired performance due to fatigue. These fatigue related factors include:

1. Time of day (circadian phase) of the events
2. Compliance of schedules with FRA established threshold (FAID compliance)
3. Peak fatigue level (FAID Score) within the 10-day schedule
4. Peak fatigue level (FAID Score) prior to event
5. Level of fatigue (FAID Score) at the time of the event
6. Total hours worked
7. Long work shifts
8. Total hours worked at night
9. Short sleep within the 10-day schedule
10. Sleep obtained prior to event
11. Long breaks (i.e., a period of two-night sleep opportunities with a non-working period in between)
12. Short breaks (i.e., less than 8 hours off-duty)

3.1 Time of Day of the Events

Two key factors that may impact the alertness of MOW workers are the time of day and the circadian phase of the individual. Research found that roadway workers have higher odds of injury during nighttime work than daytime work (Calabrese, C., Mejia, B., McInnis, C. A., France, M., Nadler, E., & Raslear, T. G., 2017). In that study, the odds of nonfatal injury for MOW employees and signalmen rose above 9:1 in the early morning hours. The relative odds of a fatal injury also increased significantly at night.

Figure 1 shows the combined frequency of accidents and incidents as a function of time of day. The frequency of accidents/incidents appears highest at 12 p.m. (12 noon). However, this may reflect an increase in opportunity for accidents/incidents given that more schedules occur during daylight hours. In 35 percent (188) of the 10-day schedules reviewed, the workers did not work hours between 2000–0600. Figure 2 shows the percentage of accidents/incidents normalized for the number of workers exposed to work at night. Incidents and accidents demonstrated a bi-modal distribution with a secondary pattern of increased frequency (peak) in the early morning hours. The increase in frequency of accidents/incidents between 2400 and 0400 is notable because there may be fewer opportunities to work at night compared to work during the day. As well, this time corresponds to a dip in circadian rhythms that generally occurs between 0200–0400 and is associated with most workers' strongest sleep drive.

Results show that the incidents and accidents demonstrated a bi-modal distribution with increased frequency (peaks) in the early morning hours and early afternoon hours which correspond to times of dips in circadian rhythms. The distribution of accidents/incidents is consistent with research that indicates accidents are more likely in the early morning hours from 0000 to 0300 (the circadian nadir) and in the early afternoon from 1200 to 1500 (the postprandial dip).

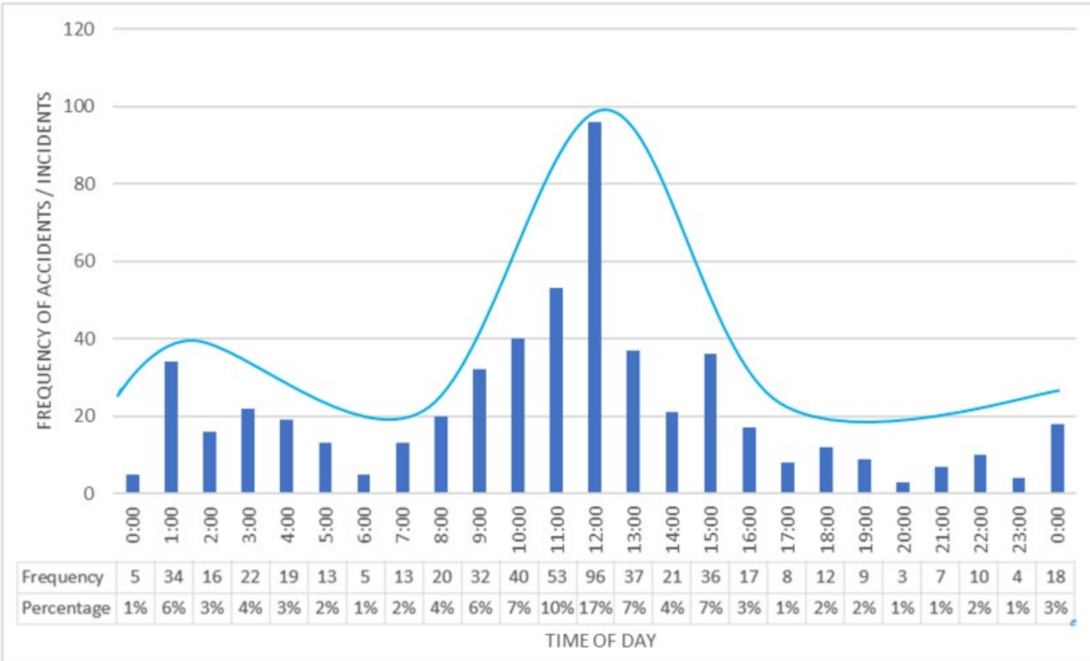


Figure 1: Frequency of Accident as a Function of the 24-hour Day (n=550)

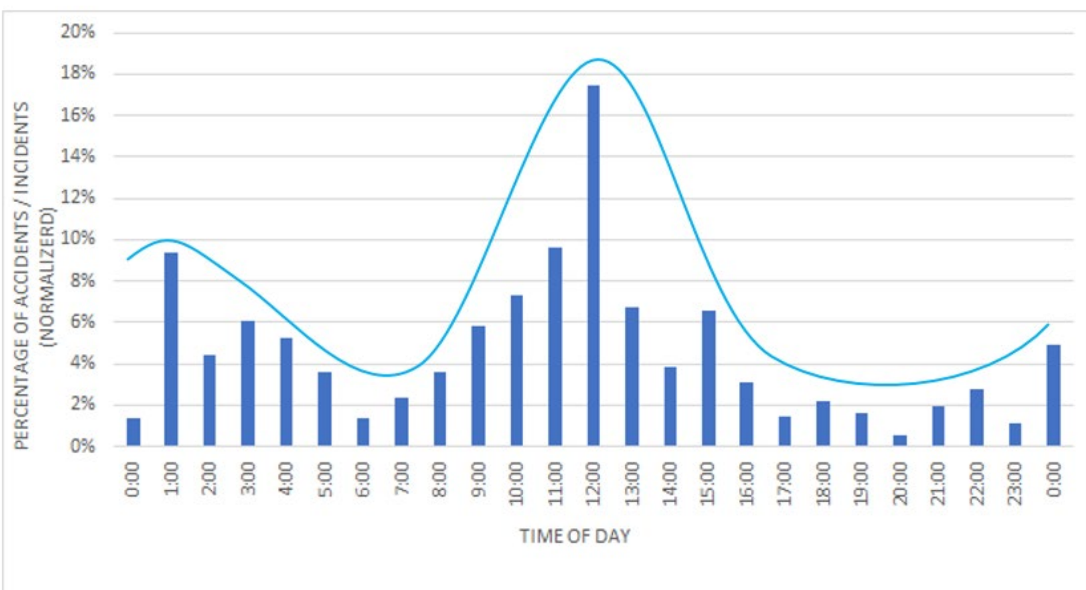


Figure 2: Frequency of Accident as a Function of the 24-hour Day (n=550) (Normalized for Exposure)

3.2 Compliance of Schedules with a Fatigue Threshold

To identify the likelihood of performance impairment associated with fatigue over the course of the 10-day schedules, a FAID Score was calculated for every minute of each schedule. FAID compliance was calculated to determine the percentage of the time that was worked in the 10-day schedule that did or did not exceed the FTL (72). If the schedule has a FAID compliance of more than 80 percent, it was considered having low to moderate fatigue risk. Correspondingly, a FAID compliance of less than 80 percent indicates that 20 percent or more of the employee's time on duty exceeded the fatigue threshold and exceeds the FAID Score benchmark figure of a 72/20 threshold established for the rail industry.

Figure 3 shows the number of 10-day schedules for all accidents, incidents and the control group, with FAID compliance grouped into five ranges: 80% or less; 80.1 to 85%; 85.1 to 90%, 90.1 to 95%, and 95.1 to 100%.

	<80%	80-85%	85-90%	90-95%	95-100%
Accident	72	25	31	53	282
Incident	22	6	5	17	37
Control	24	13	10	17	71

Figure 3: FAID Compliance of the 10-Day Schedule

These results indicate that 72 schedules (15.6%) of employees involved in accidents and 22 schedules (25.2%) of employees involved in incidents had a FAID compliance of less than 80% (i.e., 20% or more of their time on duty exceeding the FTL [72]). The results show that 24 control schedules (17.8%) had a FAID compliance of less than 80%.

A Chi-square test of independence was calculated comparing the frequency of FAID compliance in the control schedules and the schedules related to accidents. A significant interaction was not found χ^2 (1, N=598) = 0.385, p>0.05). A Chi-square test of independence was calculated comparing the frequency of FAID compliance in the control schedules and the schedules related to incidents. A significant interaction was not found χ^2 (1, N=222) = 0.178, p>0.05).

3.3 Peak Fatigue Level

Analysis was conducted to look at the highest level of fatigue prior to the event. Analysis looked at the peak FAID Score at any time over the full 10-day work schedule preceding the event. Additional analysis was conducted to look at the peak FAID Score within 1 day of the event, and at the specific time of the event.

3.3.1 Peak FAID Score Within the 10-day Schedule

The peak FAID Score was identified for each 10-day schedule to identify the highest fatigue risk prior to the event.

Figure 4 shows the number of 10-day work schedules for all accidents, incidents and the control group, with peak FAID Scores grouped into five ranges (note: FAID nominally categorizes FAID Conditions to enable assessment of the level of risk):

- less than and 62 – corresponds to a FAID Condition Green which is the FTL minus 10 points
- 62-71.9 – corresponds to a FAID Condition Yellow which is within 10 FAID Score points of the FTL
- 72-99.9 – corresponds to a FAID Condition Red which is a FAID Score above FTL but within 18 FAID Score points. This suggests a high level of risk of a human factors accident
- 100-119.9 – corresponds to a FAID Condition Red plus 18 points. This suggests an extreme level of risk of a human factors accident
- greater than 120 – corresponds to a FAID Condition Red plus 38 points. This suggest a severe level of risk of a human factors accident

These results indicate that 230 schedules (50%) of accidents and 58 schedules (67%) of incidents had a peak fatigue score that exceeded the FTL of 72. This suggests that more than approximately 50% of MOW workers that were involved in the accidents and incidents had a risk of a human factors accident greater than chance at some point in their 10-day work schedule prior to the event.

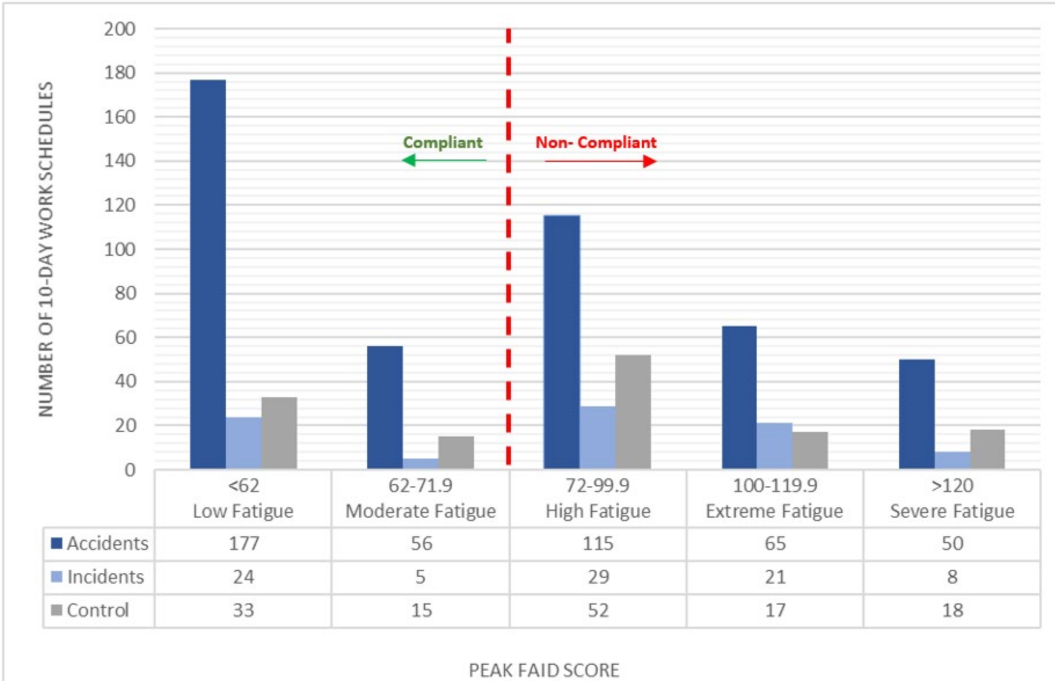


Figure 4: Peak FAID Score Within the 10-Day Schedule

The results show that 87 of the control schedules (64%) had a peak fatigue score greater than the recommended FTL of 72. A Chi-square test of independence was calculated comparing the frequency of peak fatigue scores greater than the FTL in the control schedules and the schedules related to accidents. A significant interaction was found, χ^2 (1, N=598) = 9.15, $p<0.05$). There was a significantly greater percentage of schedules with a peak fatigue score exceeding the FTL in the control schedules compared to the schedules with an accident.

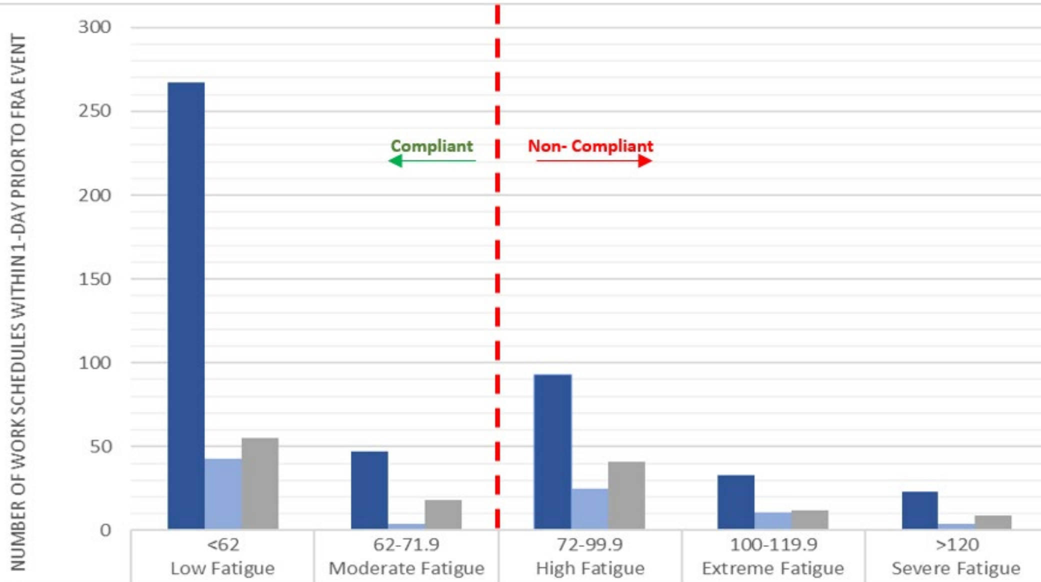
A Chi-square test of independence was calculated comparing the frequency of peak fatigue scores greater than the FTL in the control schedules and the schedules related to incidents. A significant interaction was not found χ^2 (1, N=222) = 0.115, $p>0.05$).

3.3.2 Peak FAID Score Within 1-Day of the Accident or Incident

The previous analysis looked at the peak FAID Score at any time over the full 10-day work schedule preceding the event. Additional analysis was conducted to look at the peak FAID Score closer to the time of the event. The peak FAID Score was identified for each schedule to reflect the highest fatigue risk within one work day prior to the event.

Figure 5 shows the number of work schedules within 1-day prior to all accidents and incidents (including a control group) with peak FAID Scores grouped into five ranges: less than and 62; 62 to 71.9; 72 to 99.9, 100 to 119.9, and greater than 120. As there was no accident or incident for the control schedules, the final shift in the 10-day work schedule was used to determine the peak FAID Score.

These results show that 149 schedules (32%) of accidents and 40 schedules (46%) of incidents had a peak fatigue score that exceeded the FTL of 72 within one work day prior to the event. This suggests that approximately one third or more of MOW workers involved in the accidents and incidents had a risk of a human factors accident greater than chance while at work due to fatigue at some point within the 24 hours preceding the event.



	<62 Low Fatigue	62-71.9 Moderate Fatigue	72-99.9 High Fatigue	100-119.9 Extreme Fatigue	>120 Severe Fatigue
Accidents	267	47	93	33	23
Incidents	43	4	25	11	4
Control	55	18	41	12	9

Figure 5: Peak FAID Score Within 1-Day of the Accident or Incident

There were 62 control schedules (46%) that had a peak fatigue score greater than the FTL. A Chi-square test of independence was calculated comparing the frequency of peak fatigue scores greater than the FTL in the control schedules and the schedules related to accidents. A significant interaction was found, χ^2 (1, N=598) = 8.64, $p<0.05$). Similar to the results seen in Figure 4, the control schedules had a significantly higher percentage of peak FAID Scores exceeding the FTL when compared to the work schedules within 1-day prior to the accidents.

A Chi-square test of independence was calculated comparing the frequency of peak fatigue scores greater than the FTL in the control schedules and the schedules related to incidents. A significant interaction was not found χ^2 (1, N=222) = 5.56E-05, $p>0.05$).

3.4 FAID Score at the Time of the Accident/Incident

Analysis was conducted to look at the FAID Score at the exact reported time of the event. Figure 6 shows the number of work schedules at the time of the accidents and incidents with the FAID Scores grouped into five ranges: less than and 62; 62–71.9; 72–99.9, 100–119.9, and greater than 120. In instances where the accident/incident did not occur within the 10-day schedule, no fatigue score was included. As there was no accident/incident for the control schedules, no fatigue score was included for those schedules.

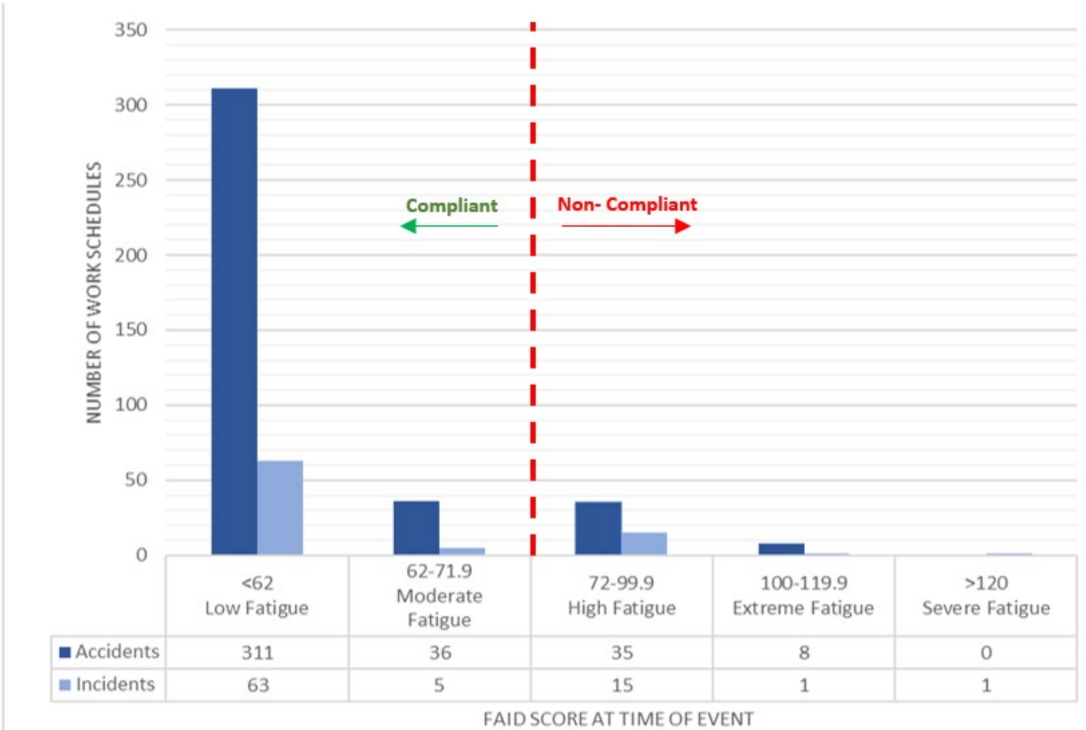


Figure 6: Fatigue Risk Scores at the Time of Event

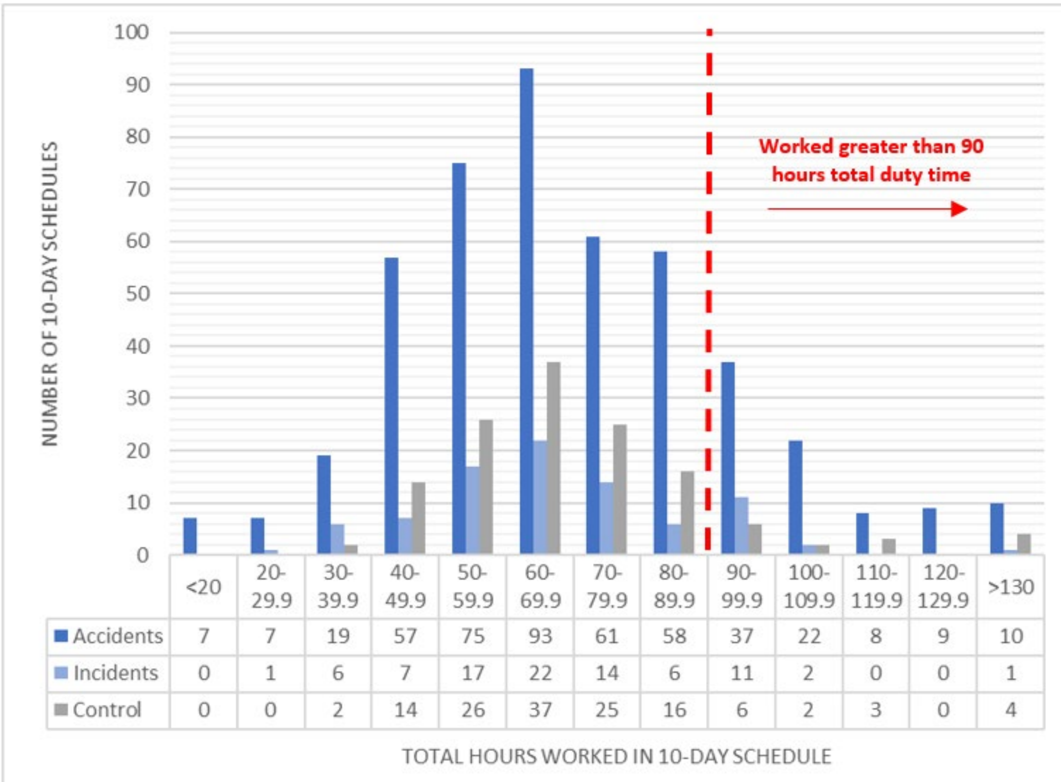
These results show that 43 schedules (11%) of accidents and 17 schedules (20%) of incidents had a fatigue score that exceeded the FTL of 72 at the time of the event. This suggests that approximately one-tenth or more of MOW workers involved in the accidents and incidents had a risk of a human factors accident greater than chance due to fatigue at the time of the event. However, because several schedules did not provide shift information corresponding to the specific time of the accident/incident, the peak fatigue score during (or within a day of) the shift when the accident/incident occurred may be a better indicator of the potential risk of fatigue near the time of the accident/incident.

3.5 Total Hours Worked in the 10-day Schedule

In many industries, there are limitations on the amount of work that can be performed over a period of one week. Limiting the hours of work is intended, in part, to allow sufficient opportunities for rest and recovery outside of work hours. Previous research by Gertler & Viale (2006) indicated that MOW workers have high levels of total hours worked. As MOW workers are not subject to limitations on hours of work, they can experience long durations of continuous work.

While there is a lack of research that focuses on 10-day schedules, there is much evidence that suggests a direct correlation between working long weekly hours and an increase in risk for accidents and incidents (Dembe, A. B., Erickson, R., Delbos, S., & Banks, S., 2005). Drew Dawson (2000) indicates that when people work for more than 50 hours per week there is increasing competition between sleep and other activities of daily living. Long working hours have been found to indirectly precipitate workplace accidents by inducing worker fatigue. Specifically, overtime schedules had the greatest relative risk of occupational injury or illness, followed by schedules with extended hours per day (12 hours or more) and extended hours per week (60 hours or more) (Dembe, A. B., Erickson, R., Delbos, S., & Banks, S., 2005).

Figure 7 shows the number of 10-day schedules (for accidents, incidents and the control group) with the total hours worked grouped into 10 hour incremental ranges. Accidents occurred most frequently on 10-day schedules where 60 to 69.9 total work hours were accumulated by an individual. Incidents occurred most frequently on 10-day schedules with 70 to 79.9 total hours. The control group's most frequent number of 10-day schedules had 70 to 79.9 total hours. The average total number of hours worked in the 10-day schedule was 70.4 (±24.7) hours for accidents, 67.9 (±19.2) hours for incidents, and 69.7 (±20.3) hours for the control group.



	<20	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-99.9	100-109.9	110-119.9	120-129.9	>130
Accidents	7	7	19	57	75	93	61	58	37	22	8	9	10
Incidents	0	1	6	7	17	22	14	6	11	2	0	0	1
Control	0	0	2	14	26	37	25	16	6	2	3	0	4

Figure 7: Total Hours Worked in the 10-Day Schedule

Although MOW workers are not subject to hours of service limitations, a limit of approximately 90 hours for a 10-day period, based on a prorated portion of a monthly limit in the Hours of Service laws for train crews on freight railroads forms a basis for comparison to MOW schedules.[3] Current results show that 86 schedules (19%) of accidents and 14 schedules (16%) of incidents had total work hours that exceeded 90 hours in a 10-day period. This suggests that approximately one-sixth or more of MOW workers that were involved in the accidents and incidents had higher fatigue risk related to a high level to total hours worked at the time of the event.

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[3] The hours of service laws limit train employees to 276 hours in a calendar month. *See* 49 U.S.C. § 21103(a)..If their time were evenly distributed throughout the month, an employee might work approximately 90 hours in a 10-day period.

There were 15 schedules (11%) in the control group that had total work hours that exceeded 90 hours in a 10-day period. A Chi-square test of independence was calculated comparing the total work hours that exceeded 90 hours in a 10-day period in the control schedules and the schedules related to accidents. A significant interaction was found, χ^2 (1, N=598) = 4.14, p<0.05). There was a significantly greater percentage of schedules with total work hours that exceeded 90 hours in a 10-day period in the schedules related to accidents compared to the control schedules.

A Chi-square test of independence was calculated comparing the total work hours that exceeded 90 hours in a 10-day period in the control schedules and the schedules related to incidents. A significant interaction was not found χ^2 (1, N=222) = 1.16, p>0.05).

3.6 Long Work Shifts

As the length of a shift increases, so does prolonged wakefulness resulting in a decrease in the subsequent sleep opportunity. Laboratory studies have shown that prolonged periods of wakefulness (i.e., 20–25 hours without sleep) can produce significant performance decrements as it pertains to vigilance and tracking tasks in simulated driving activities (Dawson, D., & Reid, K., 1997) (Lamond, N., & Dawson, D., 1998) (Blomberg, R. D., Peck, R. C., Moskowitz, H., Burns, M., & Fiorentino, D., 2005).

Numerous other studies have shown that prolonged wakefulness significantly impairs speed and accuracy, hand–eye coordination, decision making, and memory (Babkoff, H., Mikulincer, M., Caspy, T., Kempinski, D., & Sing, H., 1988) (Florica, V., Higgins, E. A., Lampietro, P. F., Lategola, M. T., & Davis, A. W., 1968) (Gillberg, M., Kecklund, G., & Akerstedt, T., 1994) (Linde, L., & Bergstrom, M., 1992). Additionally, Dinges and Durmer (2005) noted the following neurocognitive effects of sleep deprivation.

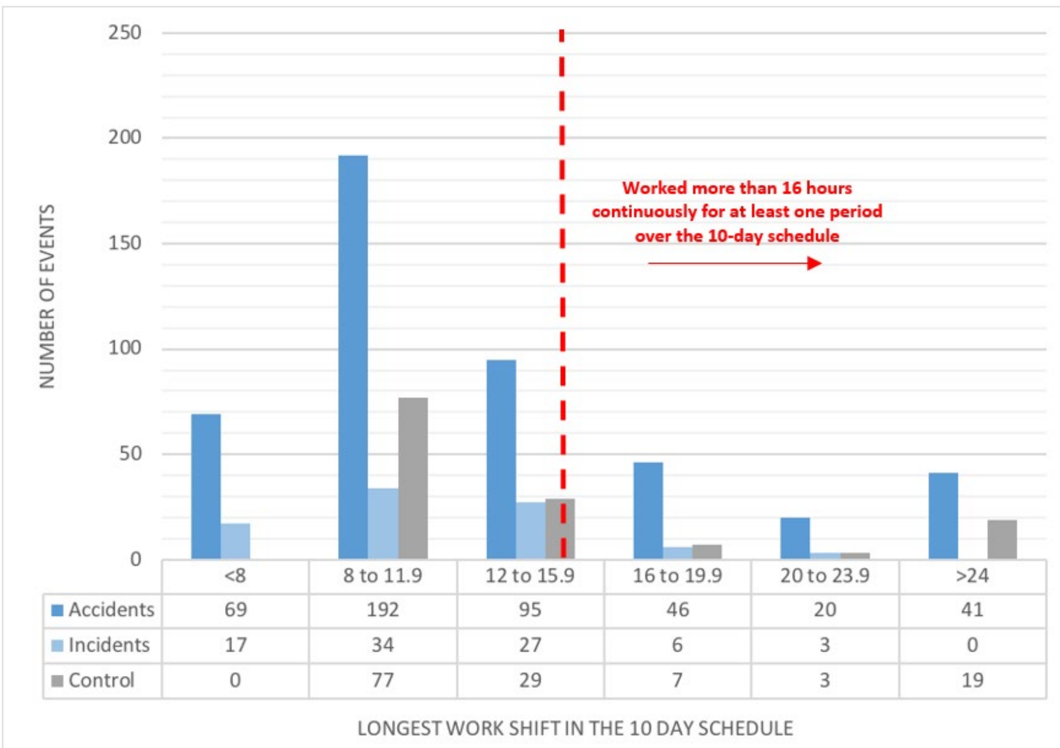
- Loss of situational awareness
- Underestimation of risk
- Flawed logic
- Hindered visual perceptions
- Slowed information processing
- Poor problem solving
- Reduced reaction time
- Decreased learning ability

Figure 8 shows the number of 10-day schedules for accidents, incidents and the control group with the longest work shift grouped into 6 ranges: less than 8 hours; 8 to 11.9 hours; 12 to 15.9 hours; 16 to 19.9 hours; 20 to 23.9 hours; and 24 hours or greater.

The longest work shift in the 10-day schedule was most frequently between 8 to 11.9 hours for both accidents and incidents. This was also the range with the highest frequency of the control schedules. The average length of the longest work shifts worked in the 10-day schedule was 14.6 (±11.9) hours for accidents, 11.9 (±3.8) hours for incidents.

Fatigue likelihood increases with shifts exceeding 14 to 16 hours. The hours of service laws and regulations allow employees to work up to 16 hours in a 24-hour period only in certain limited circumstances to respond to emergencies.[4] These results show that 107 schedules (23.1%) of accidents and 9 schedules (10.3%) of incidents occurred when the MOW worker had a long work shift of more than 16 hours in the 10-day schedule.

There were 29 control schedules (21.5%) that had long work shifts of more than 16 hours in the 10-day schedule. A Chi-square test of independence was calculated comparing frequency of schedules with at least one long work shift that exceeded 16 hours in a 10-day period in the control schedules and the schedules related to accidents. A significant interaction was not found χ^2 (1, N=598) = 0.158, p>0.05).



	<8	8 to 11.9	12 to 15.9	16 to 19.9	20 to 23.9	>24
Accidents	69	192	95	46	20	41
Incidents	17	34	27	6	3	0
Control	0	77	29	7	3	19

Figure 8: Longest Work Shift in the 10-Day Schedules

A Chi-square test of independence was calculated comparing frequency of schedules with at least one long work shift that exceeded 16 hours in a 10-day period in the control schedules and the schedules related to incidents. A significant interaction was found, χ^2 (1, N=222) = 4.625, p<0.05). There was a significantly greater percentage of schedules with at least one long work shift that exceeded 16 hours in a 10-day period in the control schedules (21.5%) compared to the schedules related to incidents (10.3%).

[4] *See* 49 U.S.C. §§ 21103(d) and 21104(c), and 49 CFR § 228.405(c). These provisions allow certain groups of employees to work up to an additional 4 hours if their work is directly related to an emergency.

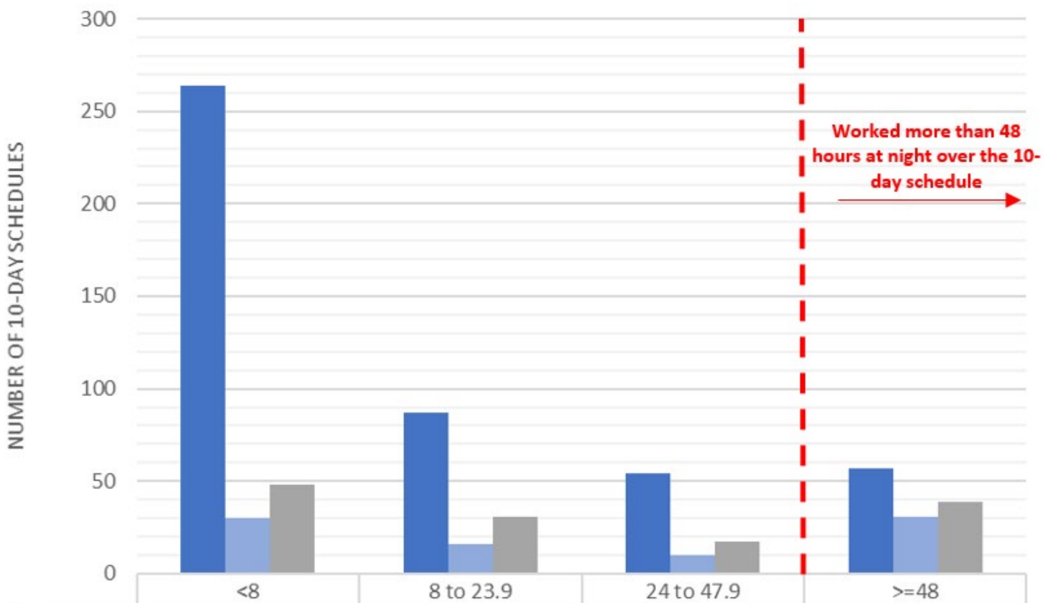
3.7 Total Hours Worked at Night

The need to work at night and sleep during the daytime does not agree with the normal time of the body clock. According to Dawson (2000), the most significant contributor to fatigue is the number of hours that an employee works and in particular, the number of night time hours.

It is recognized that workers required to sleep during daytime hours suffer from shorter sleep duration and poorer quality of sleep compared to when sleeping during dark night time hours (Roach, G., Fletcher, A., & Dawson, D., 2004). Performance errors have been noted to increase while alertness decreases over four consecutive night shifts (Walsh, J. K., Randazzo, A. C., Stone, K. L., & Schweitzer, P. K., 2004).

Research led by Folkard and Tucker of Liberty Mutual (2003) revealed that the relative risk level for an injury or incident to occur climbs by 30% when working night shift, a direct consequence of our body's design to perform optimally during daylight hours, not dark hours. They also discovered that with each successive night shift worked, the risk for an incident increases, with the most marked increase after the third night (36% increase in relative risk).

Figure 9 shows the number of 10-day schedules with the total hours worked at night (8 p.m. to 6 a.m.) grouped into 4 ranges: less than 8 hours, 8 to 23.9; 24 to 47.9 hours; and 48 or more hours. The frequency of accidents and incidents appears to be almost evenly split between less than 8 hours and more than 8 hours of night work in the 10-day schedule. For 294 events (53.6%) the schedules had less than 8 hours of accumulated night work. The control group had 38 schedules (35.6%) with less than 8 hours of accumulated night work.



	<8	8 to 23.9	24 to 47.9	>=48
Accidents	264	87	54	57
Incidents	30	16	10	31
Control	48	31	17	39

Figure 9: Total Night Work in the 10-Day Schedules

These results show that 111 of accidents (24%) and 41 of incidents (47.1%) had total night work hours that exceeded 24 hours in a 10-day period. Night work exceeded 48 hours in a 10-day period in 57 accidents (12.3%) and in 31 incidents (35.6%). These results show that MOW workers involved in the accidents and incidents had fatigue risk related to total night hours worked in the 10-day schedule prior to the event.

There were 56 schedules in the control group (41.5%) that had an accumulation of 24 hours or more of night work in the 10-day schedule. There were 39 schedules in the control group (28.9%) had an accumulation of 48 hours or more of night work. A Chi-square test of independence was calculated comparing the total night work hours that exceeded 48 hours in a 10-day period in the control schedules and the schedules related to accidents. A significant interaction was found, χ^2 (1, N=597) = 21.208, $p<0.05$). There was a significantly greater percentage of schedules with total night work hours that exceeded 48 hours in a 10-day period in the control schedules (28.9%) compared to the schedules related to accidents (12.3%).

A Chi-square test of independence was calculated comparing the total night work hours that exceeded 48 hours in a 10-day period in the control schedules and the schedules related to incidents. A significant interaction was not found χ^2 (1, N=222) = 1.114, $p>0.05$).

3.8 Duration of Sleep

Analysis was conducted to look at the sleep obtained by the MOW workers on the schedules. As actual sleep obtained by the workers was not known, FAID was used to model the amount of sleep time based on the work schedule. Analysis looked at the shortest sleep in the 10-day schedules as well as the predicted sleep obtained prior to the event.

The National Sleep Foundation, based on research from a multidisciplinary group of experts, has recommended that healthy adults ages 18–64 require 7–9 hours of sleep in a 24 hour period (Hirshkowitz, M., Whiton, K., Albert, S.M., Alessi, C., Bruni, O., DonCarlos, L., Hazen, N., Herman, J., Adams Hillard, P.J., Katz, E.S., Kheirandish-Gozal, L., Neubauer, D.N., O'Donnell, A.E., Ohayon, M., Peever, J., Rawding, R., et al., 2015). This has been further endorsed by the American Academy of Sleep Medicine and Sleep Research Society (Watson, N. F., Badr, M. S., Belenky, G., Bilwise, D. L., Buxton, O. M., 2015). The Centers for Disease Control and Prevention issued a survey that revealed 35% of U.S. adults sleep for less than 7 hours daily, including 12% who report usually sleeping for 5 hours or less (Liu, Y., Wheaton, A. G., Chapman, D. P., Cunningham, T.J., Lu, H., & Croft, J. B., 2016).

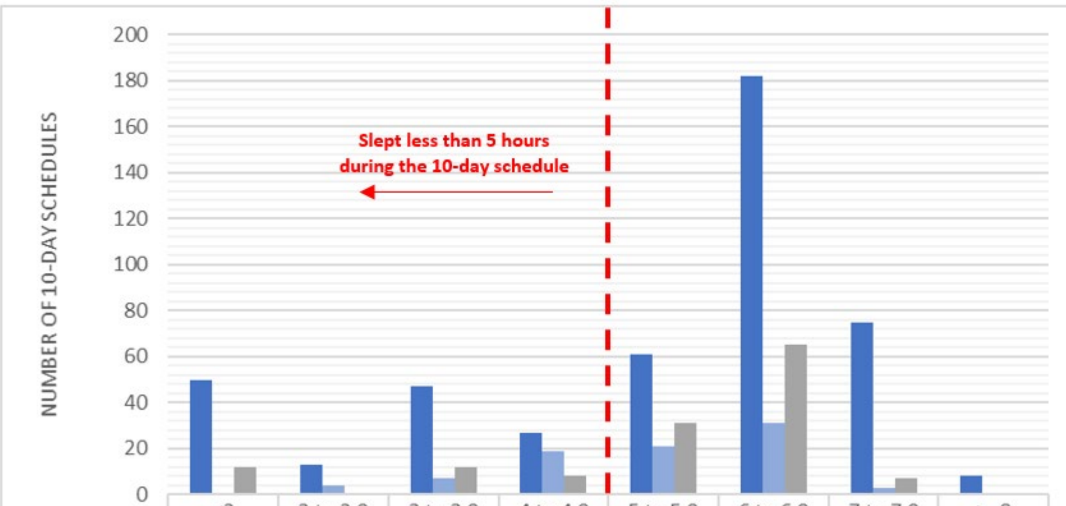
Small amounts of sleep loss occurring over consecutive nights can result in significant levels of impairment. Balkin et al. (2003) noted that when time-in-bed was restricted to five hours, vigilance was significantly impaired after the third night. Dinges et al. (2003) performed similar research, noting performance was significantly impacted after restricting time-in-bed to 4 hours over 2 days. Others who were allowed 6 hours of time-in-bed, demonstrated the ability to maintain performance until they reached between day six and eight, but posted gradual declines through the rest of the 14-day study.

As prior sleep decreases and time awake increases, the likelihood of fatigue-related symptoms, errors, and incidents also increases. Folkard et al. (2010) determined a correlation between hours of sleep and risk for injury. Using a standard frequency ratio of number of injuries per 100 workers, they discovered that those who had less than 5 hours of sleep had a frequency ratio of 7.89 versus 2.27 for those who were averaging at least 7 hours of sleep. The risk for injury goes up with reduced hours of sleep, with a significantly higher number of injuries associated with less than 5 hours' sleep. Additional research has found that performance begins to become impaired after less than five hours sleep in the 24 hours prior to work (Dorrian, J., Baulk, S. D., & Dawson, D., 2011). According to Chen et al. (2011), long periods of shortened sleep results in chronic fatigue which also translates into an increase in work injuries.

3.8.1 Shortest Sleep in the 10-day Schedules

FAID was used to estimate the hours of sleep during the 10-day schedules. Figure 10 shows the number of 10-day schedules for accidents, incidents, and the control group with the shortest estimated hours of sleep (over a 24-hour period) grouped into eight incremental ranges (less than 2 hours, 2–2.9 hours, 3–3.9 hours, 4–4.9 hours, 5–5.9 hours, 6–6.9 hours, 7–7.9 hours, and 8 or more hours).

Accidents occurred most frequently on 10-day schedules where workers shortest sleep was 6–6.9 hours of sleep. Incidents occurred most frequently on 10-day schedules where workers shortest sleep was 6–6.9 hours of sleep. The control group's most frequent number of 10-day schedules occurred for workers with 6–6.9 hours as their shortest sleep.



	<2	2 to 2.9	3 to 3.9	4 to 4.9	5 to 5.9	6 to 6.9	7 to 7.9	>=8
Accidents	50	13	47	27	61	182	75	8
Incidents	1	4	7	19	21	31	3	1
Control	12	0	12	8	31	65	7	0

Figure 10: Shortest Sleep in the 10-Day Schedules

A previous study of US railroad MOW workers found that 66% of MOW workers get less than 7 hours of sleep on workdays (Gertler, J., & Viale, A., 2006). The results from this study show that 380 schedules (82.1%) of accidents and 87 schedules (95.4%) of incidents involved MOW workers that obtained less than 7 hours sleep at some point in the 10-day schedule.

These results show that 137 schedules (29.6%) of accidents and 32 schedules (35.6%) of incidents involved MOW workers that had obtained less than 5 hours sleep in a 24-hour period at some point in the 10-day schedule. This suggests that approximately one-third of MOW workers involved in the accidents and incidents had fatigue risk related to at least one day with less than 5 hours sleep in the 10-day schedule.

In 32 control schedules (23.7%), the MOW worker had less than 5 hours sleep in a 24-hour period prior to a shift in the 10-days. A Chi-square test of independence was calculated comparing the frequency of schedules with at least one instance of less than 5 hours sleep at some point in the 10-day schedule. No significant interaction was found, χ^2 (1, N=598) = 1.78, p>0.05), between the control schedules and the schedules related to accidents. No significant interaction was found, χ^2 (1, N=222) = 3.70, p>0.05), between the control schedules and the schedules related to incidents. The incidents, accidents and control schedules had similar exposure to occurrences of less than 5 hours sleep prior to the incident/accident.

3.8.2 Sleep Prior to an Accident/Incident

The previous analyses looked at the sleep obtained in any 24-hour period over the full 10-day work schedule preceding the event. Additional analysis was conducted to look at the predicted sleep closer to the time of the event. FAID was used to estimate the sleep obtained in the 24 hours prior to the start of the shift where an accident/incident occurred.

Figure 11 shows the number of work schedules in the 24 hours prior to the accidents and incidents (or final shift) with the estimated hours of sleep grouped into eight incremental ranges (less than 2 hours, 2 to 2.9 hours, 3 to 3.9 hours, 4 to 4.9 hours, 5 to 5.9 hours, 6 to 6.9 hours, 7 to 7.9 hours, and 8 or more hours).

A total of 390 accidents (92.1% of accidents) and 78 incidents (89.7% of incidents) occurred when the MOW workers had 5 or more hours’ sleep. For the control group, the estimated sleep for the final shift was 5 or more hours in 126 schedules (93.3% of the control group).

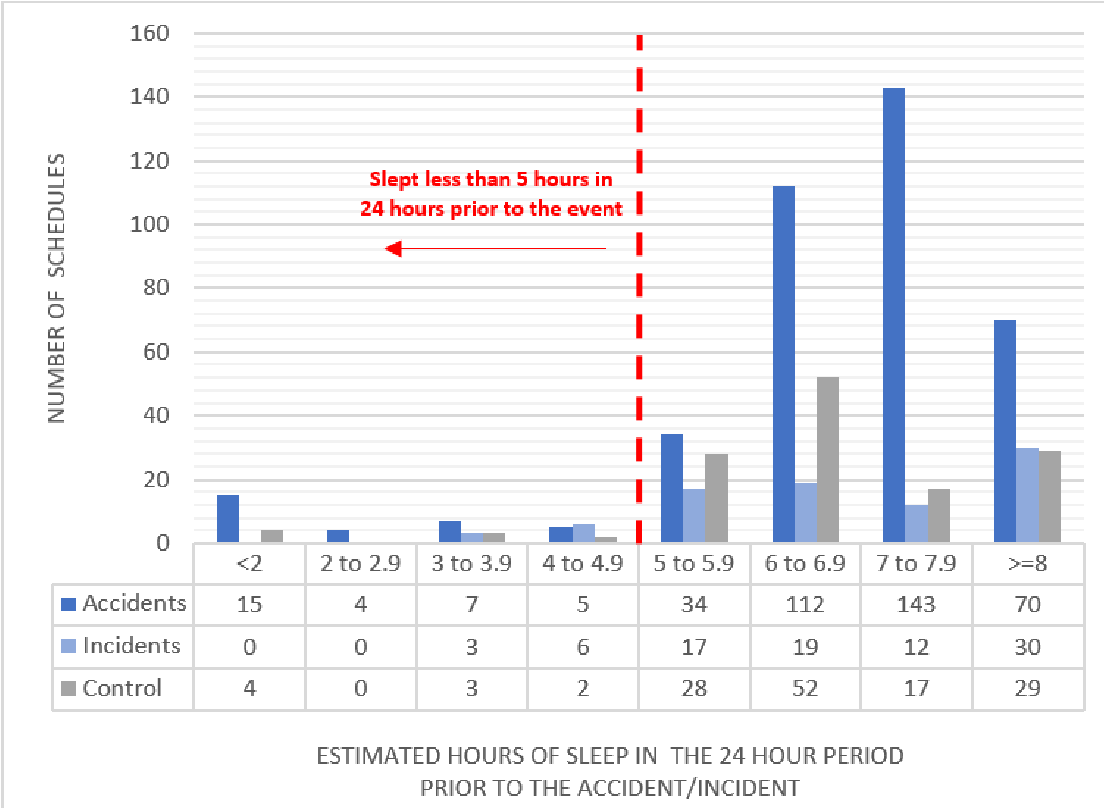


Figure 11: Sleep in the 24-Hour Period Prior to Accident/Incident

These results show that 31 schedules (7.9%) of accidents and 9 schedules (10.3%) of incidents involved MOW workers that had obtained less than 5 hours sleep in the 24 hours prior to the event. This suggests that approximately 8% or more of MOW workers involved in the accidents and incidents had fatigue risk related to at least one day with less than 5 hours sleep in the 10-day schedule.

In nine control schedules (6.7%) there were less than 5 hours of estimated sleep in the final shift. A Chi-square test of independence was calculated comparing the frequency of schedules with less than 5 hours sleep in the 24 hours prior to the event. No significant interaction was found, χ^2 (1, N=525) = 0.234, p>0.05), between the control schedules and the schedules related to accidents. No significant interaction was found, χ^2 (1, N=222) = 0.961, p>0.05), between the control schedules and the schedules related to incidents.

3.9 Long Break

Fatigue is exacerbated by increased numbers of shifts worked without a day off (Dirkx, J., 1993) (Knauth, P., 1993). Long breaks typically provide a significant opportunity to recover from sleep loss accumulated over a sequence of work periods.

In an Australian railway study, longer breaks of 48 hours reflected more sleep being obtained by the employees compared to shorter breaks (Kandelaars, K. J., Lamond, N., Roach, G. D., & Dawson, D., 2005). It is theorized that the extra hours allow family/social time without having to sacrifice sleep in order to fit them in. Additional studies have shown that two consecutive nights of recovery sleep can return performance and alertness to normal levels, following two or three 12-hour shifts (Dinges, D., Graeber, R., Rosekind, M., Samel, A., & Wegmann, H., 1996).

Several studies have looked at the requirements for recovery following a sequence of successive shifts. Åkerstedt et al. (2000) analyzed studies undertaken by the Karolinska Institute and their measure of recovery was the Karolinska Sleepiness Scale (KSS). It was noted that most of these studies indicated that three to four days were required for a full recovery after working 12 consecutive day shifts that were 12 hours long. However, one study noted that even five days were insufficient for recovery after working 14 consecutive 12-hour night shifts. It was posited that this was due to the circadian disruption as they returned to a day-oriented pattern on their days off. In the final analysis, it was concluded that 2 days should provide sufficient recovery unless the schedule design inflicts severe disruption to circadian rhythms in which case, as many as 4 days may be required. This suggests that the duration necessary for recovery is relative to the extent of the disruption of sleep preceding it.

The 10-day schedules were analyzed to determine if there was at least one long break, a period of two-night sleep opportunities with a non-working period in between. Results show that 8.6% of accidents and 10.3% of incidents occurred when the MOW worker did not have at least one long break during the 10-day schedule. There were eight control schedules (5.9%) that did not have at least one long break during the 10-day schedule. A Chi-square test of independence was calculated comparing the frequency of schedules with at least one long break. No significant interaction was found, χ^2 (1, N=598) = 1.042, p>0.05), between the control schedules and the schedules related to accidents. No significant interaction was found, χ^2 (1, N=222) = 1.461, p>0.05), between the control schedules and the schedules related to incidents.

3.10 Short Break

A short break is defined as a single sleep opportunity between work periods and is often referred to as "turnaround time." As the break between shifts decreases, so does the sleep opportunity. Short off-duty periods of less than 8 hours are associated with increased fatigue likelihood due to extended wakefulness. They also do not allow for commuting time, sufficient recovery sleep, meals, or time to take care of domestic responsibilities (Dinges, D., Graeber, R., Rosekind, M., Samel, A., & Wegmann, H., 1996) (Rosa, R., 1995) (Rosa, R., 2001).

The 10-day schedules were analyzed to determine if a non-working period of less than 8 hours occurred during that schedule. Results show that 24.8% of accidents and 18.4% of incidents occurred when a MOW worker had at least one insufficient break (<8 hours) between work periods during the 10-day schedule. Fifteen control schedules (11.1%) revealed at least one insufficient break between work periods over the 10-day schedule. A Chi-square test of independence was calculated comparing the frequency of schedules with at least one non-working period of less than 8 hours. A significant interaction was found, $\chi2$ (1, N=598) = 11.576, p<0.05), between the control schedules and the schedules related to accidents. There was a significantly higher likelihood of a short break of less than 8 hours for schedules with accidents compared to the control group. This suggests that short breaks may have contributed to an increase in accidents.

No significant interaction was found, χ^2 (1, N=222) = 2.334, p>0.05), between the control schedules and the schedules related to incidents.

4. Conclusion

This report describes the results of the analysis of the 10-day schedule data regarding maintenance-of-way (MOW) employee accidents and incidents. The objective was to determine if there were fatigue related factors contributing to these events. A biomathematical fatigue model was used to analyze the schedules and to investigate the prevalence of fatigue factors. This section describes the key findings of the study. Recommendations are provided to inform actions to reduce fatigue related risk in MOW operations. Recommendations are also provided for future research and methodological changes in future studies.

4.1 Key Study Findings

Table 1 summarizes the fatigue factors investigated in this study. Where statistical analysis (Chi-square tests of independence) demonstrated a significant interaction when compared to the control schedules, the statistical values are presented. The results provide insight into how MOW work schedules related to accidents or incidents exhibit many characteristics shown to contribute to impaired performance due to fatigue. For almost all these factors, a portion of the work schedules exceeded a fatigue risk threshold level. For any one of these factors, exceeding the fatigue risk threshold indicates elevated risk due to fatigue. It was noted that many of the schedules have more than one factor exceeding the threshold. The combination and interaction of factors can lead to an increased likelihood that human alertness and performance will be impaired.

4.1.1 Accident Schedules

Statistical analysis indicated that the percentage of the schedules exceeding the fatigue risk thresholds was significantly different for the control schedules compared to the accident schedules for some fatigue factors. Only two fatigue risk factors, long hours worked (>90 hrs.) and short breaks (<8 hrs.), had significantly more schedules exceeding the fatigue risk threshold. A larger percentage of accident schedules had more than 90 hours' work (in the 10-day period) compared to the control group. In addition, a larger percentage of accident schedules had at least one off-duty period of less than 8 hours compared to the control group. These factors might account for more of the fatigue related risk contributing to accidents.

Unexpectedly, the control schedules had significantly more schedules exceeding the fatigue risk threshold. A larger percentage of control schedules had peak FAID Scores that exceeded the threshold (72) during the 10-day schedule as well as within 1 day of the event. Also, a larger percentage of control schedules exceeded 48 hours of work at night. This suggests that peak FAID Scores and night work account for less of the fatigue related risk than might have contributed to the accidents.

The control group often had a portion of its schedules exceed the fatigue risk threshold of the various fatigue factors. Statistical analysis indicated that the percentage of the schedules exceeding the fatigue risk thresholds was not significantly different for the control schedules compared to the accident schedules for several fatigue factors (FAID compliance, long work shifts, duration of sleep, and long break). For these fatigue factors, the schedules related to accidents are not significantly different than schedules that did not involve an event, suggesting MOW workers may be routinely exposed to some fatigue risks.

Table 1: Summary of Fatigue Findings Exceeding Thresholds

Fatigue Factor and Threshold	Control Schedules	Accidents	Incidents
Time of day (circadian phase) of the event	NA[1]	Bimodal distribution of events, with peak modes at 12:00 (noon) and 01:00	Bimodal distribution of events, with peak modes at 12:00 (noon) and 01:00
FAID compliance (requires >80% of schedule below FTL of 72)	17.8% of schedules were noncompliant	15.6% of schedules were noncompliant	25.2% of schedules were noncompliant
Peak FAID score during the 10-day schedule (<72 FAID Score)	64% of schedules had a peak score that exceeded 72	50% of schedules had a peak score that exceeded 72 ***χ^2 (1, N=598) = 9.15, p<0.05***	67% of schedules had a peak score that exceeded 72
Peak FAID score within 1-day of the event (<72 FAID Score)	46% of schedules had a peak score that exceeded 72[2]	32% of schedules had a peak score that exceeded 72 **χ^2 (1, N=598) = 8.64, p<0.05**	46% of schedules had a peak score that exceeded 72
FAID score at the time of the event (<72 FAID Score)	NA[1]	11% of schedules had a score that exceeded 72	20% of schedules had a peak score that exceeded 72
Total hours worked in the 10-day schedule (<90 hours)	11% of schedules exceeded 90 hours	19% of schedules exceeded 90 hours. **χ^2 (1, N=598) = 4.14, p<0.05)**	16% of schedules exceeded 90 hours
Total hours worked in the 10-day schedule (<90 hours)	11% of schedules exceeded 90 hours	19% of schedules exceeded 90 hours. **χ^2 (1, N=598) = 4.14, p<0.05)**	16% of schedules exceeded 90 hours
Long work shifts (<16 hours)	21.5% of schedules had a long work shift of more than 16 hours	23.1% of schedules had a long work shift of more than 16 hours	10.3% of schedules had a long work shift of more than 16 hours. **χ^2 (1, N=222) = 4.625, p<0.05)**
Total night hours (2000-0600) worked in the 10-day schedule (<48 hours)	28.9% of schedules exceeded 48 hours of work at night	12.3% of schedules exceeded 48 hours of work at night **χ^2 (1, N=597) = 21.208, p<0.05)**	35.6% of schedules exceeded 48 hours of work at night

Fatigue Factor and Threshold	Control Schedules	Accidents	Incidents
Short sleep in the 10-day schedule (≥ 5 hours)	23.7% of schedules had at least one sleep that was less than 5 hours	29.6% of schedules had at least one sleep that was less than 5 hours	35.6% of schedules had at least one sleep that was less than 5 hours
Sleep obtained prior to the event (≥ 5 hours)	6.7% of schedules had less than 5 hours sleep[2]	7.9% of schedules had less than 5 hours sleep	10.3% of schedules had less than 5 hours sleep
Long Break (a period of 2-night sleep opportunities with a non-working period in between) [≥ 1 long break in 10-days]	5.9% of schedules did not provide at least one long break during the 10-day schedule	8.6% of schedules did not provide at least one long break during the 10-day schedule	10.3% of schedules did not provide at least one long break during the 10-day schedule
Short Break (an off-duty period of less than 8 hours) [<1 short break in 10-days]	11.1% of schedules had at least one short break during the 10-day schedule	24.8% of schedules had at least one short break during the 10-day schedule **χ^2 (1, N=598) = 11.576, p<0.05)**	18.4% of schedules had at least one short break during the 10-day schedule

[1] Not applicable given there was no event.
[2] The final shift in the selected 10-day work schedule was used as there was no event.

4.1.2 Incident Schedules

Statistical analysis indicated that the percentage of the schedules exceeding the fatigue risk threshold was significantly different for the control schedules compared to the incident schedules for only one of the fatigue factors. A significantly smaller percentage of schedules with a long work shift exceeded 16 hours compared to the control schedules. This significant difference indicates that long work shifts may account for less of the fatigue related risk that might have contributed to the incidents.

Statistical analysis indicated that the percentage of the schedules exceeding the fatigue risk threshold was not significantly different for the control schedules compared to the incident schedules for several fatigue factors (FAID compliance, peak FAID Score, total hours worked, work at night, duration of sleep, long break, and short break). For these fatigue factors, the schedules related to the incidents are not significantly different than the schedules that did not involve an event. For these schedules, MOW workers may be routinely exposed to fatigue factors.

4.1.3 Fatigue Factors in Control Schedules

The results showed that the control group often had a proportion of its schedules exceed the fatigue risk threshold of the various fatigue factors. Also in most of the fatigue factors, the control schedules were not significantly different than the schedules for the accidents and the incidents. In a few cases, the control schedules had significantly less fatigue related risk than the accident and incident schedules.

It is possible that MOW workers are regularly exposed to fatigue factors due to the nature of their schedules. The schedules with accidents had only one fatigue factor with a significantly larger percentage than in the control schedules, which was with respect to having an off-duty period of less than 8 hours. While this may have accounted for some of the fatigue related risk for accident schedules, it does not fully account for why an accident occurred.

The lack of differences between the accident schedules and the control schedules may be due to the source of the data. To provide a baseline comparison group, 135 random 10-day schedules were collected from one railway. These schedules were collected from the same participants that had experienced an FRA reportable accident but for a time period at least 1 month prior to the accident. Although the 10-day schedules were collected when there was no accident, the schedules were collected from MOW workers who would experience an accident in the near future. These individuals may have been more likely than other MOW workers to have schedules that exhibited the fatigue factors.

4.2 Recommendations

Recommendations are provided to guide the use of these results to inform actions to reduce fatigue related risk in MOW operations.

4.2.1 Integrate Scheduling Strategies to Limit Fatigue Risk Exposure

Schedules of MOW workers involved in accidents and incidents were analyzed for several of the fatigue factors. For each parameter, a percentage of MOW workers were exposed to a degree of fatigue risk that exceeded the fatigue risk threshold, thereby increasing the likelihood that human alertness and performance will be impaired. This fatigue risk would likely increase further where it is noted that many of other fatigue factor thresholds were exceeded. It is recommended that railroads systematically conduct routine analysis of their MOW schedules to identify and monitor the degree to which they exceed fatigue risk thresholds. Once identified, the railroad's fatigue risk management programs should address the violations and exceedances through risk mitigation and corrective actions to reduce the fatigue risk exposure.

i. Time of day (circadian phase) of the events: Recognize the increased likelihood of accidents and incidents between 1200–1600 and 2400–0400.

ii. Compliance of schedules with FRA established fatigue threshold (FAID compliance): Identify and address schedules for which FAID compliance is less than 80% (i.e., greater than 80% of FAID Scores of an individual's schedule should be below the FTL of 72).

iii. Peak fatigue level (FAID Score) within the 10-day schedule: Identify and address aspects of schedules that cause peak FAID Scores that exceed the FTL of 72.

iv. Peak fatigue level (FAID Score) prior to event: Identify and address aspects of schedules that cause peak FAID Scores that exceed the FTL of 72.

v. Level of fatigue (FAID Score) at the time of the event: Identify and address aspects of schedules that cause peak FAID Scores that exceed the FTL of 72.

vi. Total hours worked: Identify and address schedules that exceed 90 hours of total work over a 10-day period.

vii. Long work shifts: Identify and address schedules that exceed 16 hours of continuous work.

viii. Total hours worked at night: Identify and address schedules that exceed 48 hours of night work over a 10-day period.

ix. Short sleep within the 10-day schedule: Identify and address schedules for which the predicted/modelled hours of sleep is less than 5 hours.

x. Sleep obtained prior to event: Identify and address schedules for which the predicted/modelled hours of sleep is less than 5 hours.

xi. Long breaks: Identify and address schedules that do not provide at least one long break (a period of 2-night sleep opportunities with a non-working period in between) over a 10-day period.

xii. Short breaks: Identify and address schedules that have at least one short break (less than 8 hours off-duty) over a 10-day period.

4.2.2 Potential Education for FRA, Industry, and MOW Workers

Results of this study may be used to highlight the many fatigue risk factors related to MOW schedules. Across all the metrics, the control schedules for the MOW workers had exposure to factors that contribute to fatigue-related risk. This suggests that the MOW workers could be exposed to an elevated level of fatigue risk on many independent measures. When consideration is given to the potential interaction and impact of multiple fatigue risk factors, there appears to be a high level of fatigue related risk for MOW workers. Education and awareness sessions can highlight the individual and collective performance impact of the fatigue risk factors such as inadequate sleep and strategies to improve alertness while on shift. As part of fatigue risk management programs, railroads may want to provide more fatigue education to MOW workers and their leadership teams related to the fatigue risk factors and thresholds described in this report.

4.2.3 Recommendations for Work/Rest Regulations

The fatigue factors and the thresholds used in this study may be used to guide scheduling and work/rest regulation of MOW work hours. A significantly larger percentage of accident schedules had more than 90 hours' work (in the 10-day period) compared to the control group. In addition, a significantly larger percentage of accident schedules had at least one off-duty period of less than 8 hours compared to the control group. These were the only fatigue factors with significantly greater likelihood of fatigue related risk compared to the control group. As such, priority may be given to limiting exposure to long work hours (>90 hrs. in a 10-day period) and ensuring the provision of off-duty periods of more than 8 hours for MOW operations.

4.3 Recommendations for Future Research

The following methodological improvements are suggested based on the results of this study:

- Due to the selection of the control schedules from workers who had a known accident/incident, they may have been more predisposed to high fatigue risk factors than other MOW workers. Additional analysis may be conducted by FRA to consider schedules obtained from MOW workers who had not experienced recent accidents or incidents. Future research should gather additional schedules from MOW workers for which there were no accident or incidents. These schedules may provide a more complete set of comparison data to determine if MOW workers are regularly exposed to fatigue factors.
- Schedules should include at least 14 continuous days up to the day of the event. Schedules worked up to seven days prior to a shift may impact the fatigue score calculated by a BFM. A 14-day schedule will ensure that there is a full week of valid fatigue scores prior to the event. This would also facilitate reporting of results for a validated 7-day time frame. This would provide improved consistency for reporting the study findings in metrics that align with current regulations, often framed in a 7-day time frame.
- For all individuals who had an accident or incident, at least one 14-day schedule should be provided for a period at least 2 months prior to the event. This will provide a within-subjects schedule for comparison.
- As non-MOW workers may be subject to Hours of Service laws or regulations, they could provide a good basis for comparison to MOW schedules. Additional analysis may be conducted to consider schedules from non-MOW workers.
- Summary information provided by the railroads should be verified to include a minimum set of information. This would require schedule information for the complete time period as well as the shift on which the event occurred. Information about the event should be provided that would allow for coding of additional human factors (type of errors) and fatigue-related characteristics (commuter, sleep away from home, physical workload, work environment) to be completed. Demographics about the workers involved may also help to allow for consideration of other fatigue related characteristics such as age, caffeine use, medication use, diagnosis of sleep disorders, etc.

5. References

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Abbreviations and Acronyms

Abbreviations	Acronyms
BFM	Biomathematical Fatigue Model
CFR	Code of Federal Regulations
FTL	FAID Score Tolerance Level
FAID®	Fatigue Audit Interdyne™
FRA	Federal Railroad Administration
KSS	Karolinska Sleepiness Scale
MOW	Maintenance-of Way