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Fatigue Status of the U.S. Railroad Industry

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13. ABSTRACT (Maximum 200 words)
This report draws on the results of several prior studies, all conducted with similar methodology, to characterize the prevalence of employee fatigue in the U.S. railroad industry. Data from logbook surveys of signalmen, maintenance of way workers, dispatchers, and train and engine service employees were combined to examine the relationship between work schedules and sleep patterns. Railroaders make up for lack of sleep on workdays by sleeping longer on rest days. This strategy is used to a greater extent among by certain groups such as signalmen working four 10-hour days, first shift dispatchers, and train and engine service (T&E) workers on jobs with a fixed start time. T&E workers in passenger service with a split assignment have a shorter primary sleep period than those working straight through or working extra board assignments, but they have similar total daily sleep because they sleep during their interim release. Overall, U.S. railroad workers are more likely than U.S. working adults to get less than 7 hours of total sleep on workdays, but railroad workers average more total sleep when sleep on workdays and rest days are combined. According to the FAST software tool, the effectiveness (inverse of fatigue) for each group, based on logbook data for work and sleep, indicates that T&E workers and third shift dispatchers have the most fatigue exposure and passenger T&E workers have the least. Railroad workers in all groups had less fatigue exposure than those involved in human factors accidents.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

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[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

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1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

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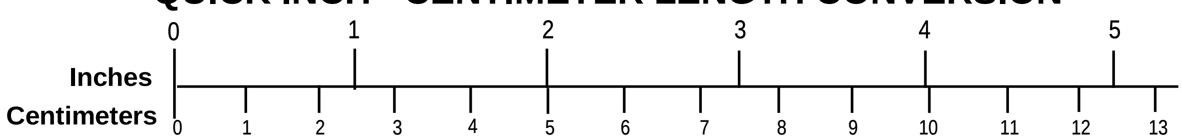

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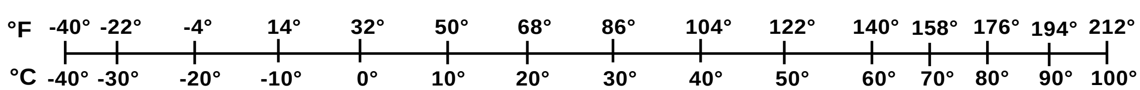

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Executive Summary

How fatigued are safety-critical railroad employees such as Train and Engine (T&E) workers, passenger T&E workers, signalmen, Maintenance of Way (MOW) workers and dispatchers, and how does their level of fatigue affect the safety of railroad operations? Are statutory or regulatory limitations on hours of work sufficient to prevent worker fatigue? Fatigue is largely a function of sleep and circadian rhythms. Sleep, in turn, is a function of work schedules. Work duration, the time of day (TOD) of work, and schedule variability are aspects of work schedules that determine when sleep can occur. Fatigue exposure is determined largely by work schedules, and fatigue exposure determines fatigue risk and the probability of human factor accidents.

In 2001, FRA began examining the fatigue status of safety-critical railroad employees by using logbooks to collect work and sleep data over a period of 2 weeks from a representative sample of employees in each group. Concurrently, FRA supported the application of the Fatigue Avoidance Scheduling Tool (FAST) to railroad employee schedules. FAST is a biomathematical model that can be used to assess fatigue risk in work schedules and plan schedules that reduce that risk.

Key findings of this report are as follows:

- The risk of a human factors accident is elevated 11 to 65 percent above chance by exposure to fatigue.
- The economic cost of a human factors accident when an employee is very fatigued is approximately $1,600,000, compared to $400,000 in the absence of fatigue.
- Amount of sleep and the time of day when sleep occurs account for 85 to 96 percent of fatigue exposure. Work schedules determine the amount and time of day of sleep.
- Dispatchers and T&E workers have the highest exposure to fatigue. They are also the groups that have the longest work hours and work at night.
- T&E as a group has significant fatigue exposure, but passenger T&E is the group with the least fatigue exposure. The predictability of passenger T&E schedules and less nighttime work explains this difference.
- The fatigue exposure of all groups is less than that of employees involved in human factors accidents, which indicates a relationship between fatigue and accidents.
- Significant differences resulting from job type and schedule exist in the sleep patterns of railroad workers. Analysis of data collected through a logbook study allows for identification of the differences that are not otherwise apparent.
- The sleep pattern of railroad workers differs from that of U.S. working adults. Railroad workers are more likely to get less than 7 h of total sleep on workdays, which puts them at risk of fatigue. On average, however, they obtain more total sleep than U.S. working adults, when total sleep hours on workdays *and* rest days are combined.
- Railroad workers in all groups reported sleep disorders that exceed U.S. norms for working adults. Of these, all but 2.4 percent were receiving treatment.
- The FRA fatigue model (FAST) provides a valid method of assessing fatigue exposure as

a function of work schedule and sleep pattern.

These findings suggest that strategies for reducing railroad worker fatigue include improving the predictability of schedules and educating workers about human fatigue and sleep disorders.

The research in this report was conducted prior to implementation of the Railroad Safety Improvement Act of 2008 (RSIA) which made significant changes to limitations on hours of work for railroad employees. Consequently, the information in this report can serve as a baseline for examining the sufficiency of existing statutory or regulatory limitations on hours of work to prevent worker fatigue.

1. Introduction

Statutory or regulatory limitations on hours of work may not be sufficient to prevent railroad worker fatigue. FRA suspected as much with regard to railroad employees and in the late 1980s began conducting research to determine whether or not existing regulations were effective in preventing railroad worker fatigue. At that time, FRA sponsored two studies: an initial one to collect quantitative data on locomotive engineer fatigue and stress (Pollard, 1996) and a subsequent simulator study (Thomas, Raslear, and Kuehn, 1997). The simulator study found that locomotive engineers working strictly within hours of service limits accumulated a progressive sleep debt over consecutive days. Since this initial research, FRA has sponsored a subsequent survey of train and engine crews, as well as surveys of other railroad worker groups (Gertler and DiFiore, 2009, 2011; Gertler and Viale, 2006a, 2006b, 2007). FRA has also supported the development of a biomathematical model to analyze work schedules for fatigue risk and has used this model to assess the risk of fatigue-related railroad accidents (Hursh, Raslear, Kaye, and Fanzone, 2006, 2008; Hursh, Fanzone, and Raslear, 2011).

1.1 Hours of Service Law and Regulation

Federal laws governing railroad employees' hours of service date back to 1907 with the enactment of the Hours of Service Act.[1] These laws, which are currently codified as amended (49 U.S.C. §§ 21101-21109) and collectively referred to in this document as the hours of service laws (HOS Law), are intended to promote safe railroad operations by limiting the hours of service of three categories of railroad employees, thereby ensuring that these employees receive adequate opportunities for rest in the course of performing their duties.[2] The groups of railroad employees covered by the HOS Law are (1) "signal employees," (2) "dispatching service employees," and (3) "train employees" (i.e., "individual[s] engaged in or connected with the movement of a train, including a hostler," (49 U.S.C. § 21101(5))). In this document, "train employees" are generally referred to as "train and engine service workers" or "T&E workers."

Prior to passage of the RSIA, a covered worker's on-duty period was limited to a maximum of 12 consecutive hours in a 24-hour period. After working 12 h, the worker had to have at least 12 h off duty before returning to work. If the employee worked less than 12 h in a 24-hour period, then the required off-duty period was 8 h. The covered worker was permitted to work a total of 16 non-consecutive h in a 24-hour period if the individual had at least 8 h off duty between the two 8-hour work periods. There was no provision limiting the number of consecutive days or guaranteeing rest days. Limits on dispatching service employees differed from those that applied to signal employees and T&E workers and have not changed with passage of the RSIA. A dispatcher may not remain on duty for more than 9 h, whether consecutive or in the aggregate, in any 24-hour period, in operations that employ two or more shifts. This means that once the dispatcher has worked for 9 h, he or she must have 15 h of rest.

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[1] See Pub. L. No. 59-274, 34 Stat. 1415 (1907), *repealed by* 108 Stat. 1379-1380 in 1994. See also footnote 2 of this report.

[2] See Pub. L. No. 103-272, 108 Stat. 745-1401 (1994) (which, *inter alia*, repealed the existing general and permanent Federal rail safety statutes and revised and re-enacted them without substantive change as positive law in title 49 of the U.S. Code).

The enactment on October 16, 2008, of the RSIA (Pub. L. No. 110-432, Div. A) not only changed the statutory limits on work hours for T&E workers in freight service (freight T&E workers), effective July 16, 2009, and kept T&E workers in intercity or commuter rail passenger service (passenger T&E workers) temporarily subject to the pre-RSIA statutory limits, but also gave FRA, by delegation, the authority to prescribe regulations for passenger T&E workers that differ from the amended statutory requirements applicable to T&E workers in freight service.[3] Pursuant to 49 U.S.C. § 21102(c), effective July 16, 2009, with respect to freight T&E workers, the RSIA (specifically, 49 U.S.C. § 21103 as amended by the RSIA, which the statute designates as “new Section 21103”) establishes limits per calendar month on service performed for a railroad and on time in or awaiting deadhead to final release; increases the quantity of the statutory minimum off-duty period after being on duty for 12 h in broken service from 8 h of rest to 10 h of rest; prohibits railroads’ communication with such workers during certain minimum statutory rest periods; and establishes mandatory time off duty for such workers of 48 h after initiating an on-duty period on 6 consecutive d, or 72 h after initiating an on-duty period on 7 consecutive d (49 U.S.C. § 21103).[4]

The new regulation on hours of service for T&E workers in commuter and passenger service went into effect on October 15, 2011. This regulation leaves unchanged the limitation of 12 consecutive h of time on duty in a 24-hour period and the mandatory off-duty periods, but does limit the number of days of consecutive work for those who work overnight assignments. Because some commuter and passenger service includes overnight work, the rule defines a “Type 2” assignment as one that includes time on duty between 8 p.m. and 4 a.m. If the employee’s work schedule includes at least one Type 2 assignment, there is a new limit on the number of consecutive days of work. Railroads operating commuter and passenger service must also analyze the work schedules of their passenger train employees using an FRA-approved model of human performance and fatigue to identify schedules with an unacceptable level of fatigue exposure. Railroads must identify work schedules which exceed the fatigue threshold more than 20 percent of the work time and propose fatigue mitigation actions subject to FRA approval.

The research described in this report was conducted prior to the changes in the HOS Law described above.

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[3] See Section 108 of RSIA; 49 U.S.C. §§ 21102(c), 21103, and 21109(b)-(c); and FRA Interim Statement of Agency Policy and Interpretation at 74 Fed. Reg. 30665 (June 26, 2009).

[4] In particular, Section 108(d) of the RSIA, which became effective on October 16, 2008, provided that the requirements described above for train employees would not go into effect on July 16, 2009, for train employees of commuter and intercity passenger railroads (49 U.S.C. § 21102(c)). Section 108(d) further provided that these train employees, who provide commuter or intercity passenger rail service, would continue to be governed by the old HOS Law (as it existed immediately prior to the enactment of the RSIA, at 49 U.S.C. § 21103 prior to its 2008 amendment (which the statute designates as “old Section 21103”)), until the effective date of regulations promulgated by the Secretary (49 U.S.C. § 21102(c)). However, if no new regulations are in effect before October 16, 2011, the provisions of new Section 21103 would be extended to the passenger T&E workers at that time. Id.

Section 108(e) of the RSIA specifically provides the Secretary with the authority to issue hours of service rules and orders applicable to train employees engaged in commuter rail passenger transportation and intercity rail passenger transportation (as defined in 49 U.S.C. § 24102), that may be different from the statute applied to other train employees (49 U.S.C. § 21109(b)).

1.2 FRA Research on Railroad Worker Fatigue

FRA's first exploration of railroad worker fatigue with empirical data was a work/rest diary survey of over 200 locomotive engineers (Pollard, 1996). This research found that while the average locomotive engineer obtained only 20 minutes (min) less sleep than the average person, locomotive engineers who started work between 10 p.m. and 3 a.m. averaged only about 5 h of sleep. This result indicates the importance of circadian rhythms and TOD in the amount of sleep that workers can get. Thomas, Raslear, and Kuehn (1997) also found that locomotive engineers in a simulator study, working strictly within the HOS Law, accumulated a progressive sleep debt over a period of days because their work was scheduled at a progressively earlier TOD each day. Engineers working a 10-hour shift with 12 h off duty averaged only 4.6 h of sleep. The engineers reported a progressive decrease in subjective alertness across the duration of the study, and performance of safety-sensitive tasks degraded during the same time period. Thomas *et al*. concluded that the HOS Law allows work schedules that degrade job performance and reduce the safety of railroad operations. However, this conclusion was questioned because there was little empirical evidence to support it. FRA had ample anecdotal evidence, mainly complaints from labor, indicating that fatigue was an important safety concern. The National Safety Transportation Board (NTSB) had investigated several railroad accidents and concluded that fatigue was a contributing factor (e.g., NTSB, 1991a, 1991b). Ultimately, NTSB added fatigue to its Most Wanted List of safety issues, and noted the following in a 1999 Safety Report (NTSB, 1999):

> According to a Safety Board analysis of Federal Railroad Administration (FRA) data from January 1990 to February 1999, only 18 cases were coded "operator fell asleep" as a causal or contributing factor. The Board believes that 18 cases in more than 9 years underestimates the actual number of cases in which fatigue might have been involved. For example, two Safety Board investigations—Sugar Valley, Georgia (August 9, 1990), and Corona, California (November 7, 1990)—in which fatigue was cited by the Safety Board as a causal factor were not coded in the FRA database as fatigue-related but rather as a failure to comply with signals.
>
> In testimony before the Senate Subcommittee on Surface Transportation and Merchant Marine on September 16, 1998, the Administrator of the FRA stated that "about one-third of train accidents and employee injuries and deaths are caused by human factors. We know fatigue underlies many of them."
>
> In summary, although the data are not available to statistically determine the incidence of fatigue, the transportation industry has recognized that fatigue is a major factor in accidents, as was clearly demonstrated at the Safety Board's 1995 symposium on fatigue. Further, the Safety Board's in-depth investigations have clearly demonstrated that fatigue is a major factor in transportation accidents.

In fact, the FRA accident cause code, H104 Employee Asleep, is the only accident code related to fatigue. As can be seen in Figure 1, very few accidents to date have been assigned a fatigue cause code by railroads, and this, in turn, can be taken as evidence that fatigue is not a safety problem in the railroad industry. Consequently, FRA's Office of Research and Development saw a need to document the incidence of fatigue in the railroad industry in a scientifically rigorous way and to determine the relationship between accidents and fatigue.

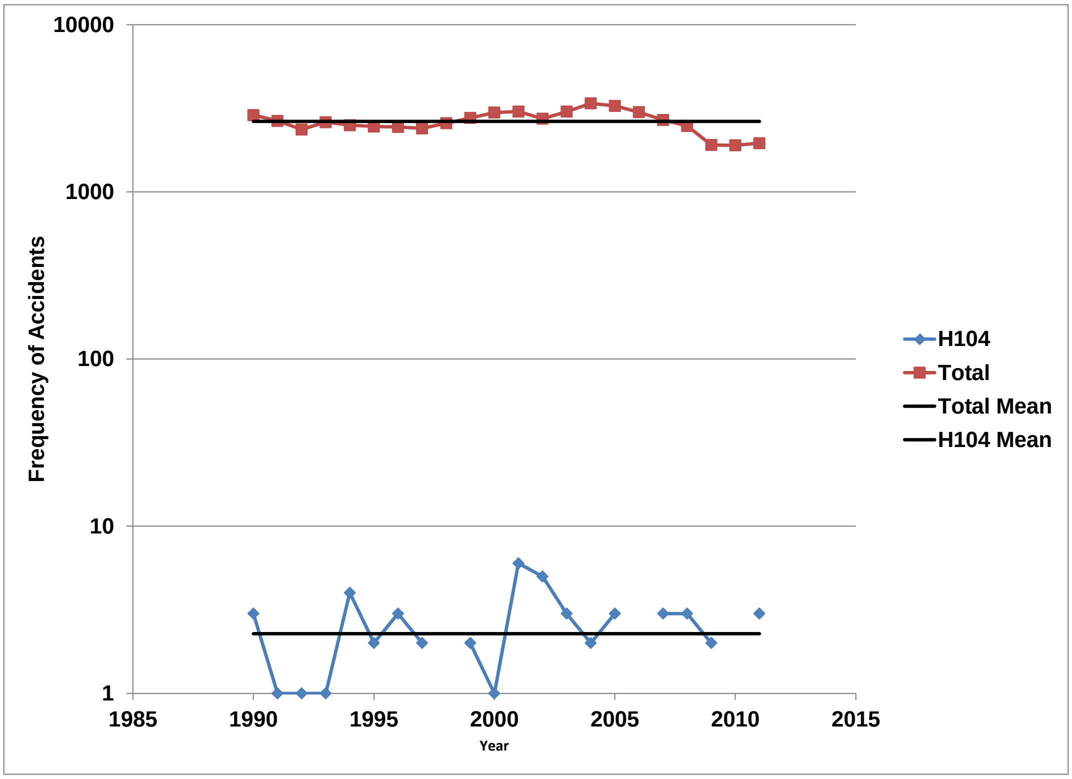

Figure 1. Frequency of All Train Accidents and H104, Employee Asleep, Accidents From 1990 to 2011 (frequency scale is logarithmic)

It was already widely-recognized in the scientific community at the time of the Pollard and Thomas *et al.* studies, that sleep is regulated by at least two processes (Borbely, 1982; Daan, Beersma and Borbely, 1984). One process is the homeostatic need for sleep by which an accumulating sleep debt increases the propensity to fall asleep. The second process is the circadian fluctuation in the propensity to fall asleep as a function of TOD. When these two processes conflict (e.g., there is a substantial sleep debt, but it is 10 a.m., or there is minimal sleep debt and it is 1 a.m.), it is difficult to determine the outcome without a mathematical model of the processes. This was recognized in the Thomas *et al.* study where a simple sleep model was described in Appendix I of that report and used to analyze performance changes as a result of work schedule characteristics. The success of this analysis indicated the importance of sleep/fatigue models and motivated FRA to develop a fatigue model specifically for use by the railroad industry in the analysis of work/sleep schedules and accidents. Section 4 provides a more complete description of the development of the FRA fatigue model.

Because railroading is a round-the-clock, 7-days-a-week operation, and because a wide array of workers are needed both to operate and maintain the Nation's railroads, other crafts besides T&E may also be subject to fatigue. In 2001, FRA began examining the fatigue status of these other crafts. At that time, FRA initiated the first of five field studies to gather data on the work schedules and sleep patterns of railroad workers. The first study focused on signalmen, followed by MOW workers, and then railroad dispatchers. The last two studies characterized T&E workers, first as a group and then only those in passenger operations. Each of these studies used a consistent methodology and collected data from a random sample of each target population. In each case, estimates of accuracy and target error rate determined the size of the sample. Because the data collection methodology was consistent across the studies, combining these data across the groups for further analysis is possible.

Concurrent with the studies to characterize the work schedules and sleep patterns of railroad workers, FRA supported the application of the Fatigue Avoidance Scheduling Tool (FAST) to railroad employee schedules. FAST is a biomathematical model that can be used to assess the risk of fatigue in work schedules and to plan schedules that reduce this fatigue. The model takes into account the TOD when work occurs and predicts sleep based on the work schedule. Using work histories from employees involved in 400 human factors and 1,000 non-human factors accidents, Hursh, Raslear, Kaye, and Fanzone (2006, 2008) used FAST to calculate effectiveness (inverse of fatigue). The data from Hursh *et al*. showed that there is a reliable relationship between the TOD of human factors accidents and the expected normal circadian rhythm. This circadian pattern was not reliably present for nonhuman factors accidents. As will be discussed in Section 5, Hursh *et al.* also established a relationship between the risk of a human factors accident and fatigue.

1.3 Objectives

The objective of this report is to provide the first comprehensive picture, based on the five field studies mentioned above, of fatigue among U.S. railroad industry employees performing safety-sensitive work. This report provides a composite summary of the work schedules and sleep patterns of U.S. railroad workers based on analysis of work and sleep patterns using the FAST fatigue model. This information serves as a benchmark for assessing future changes in worker fatigue that may result from the now current hours of service limits mandated by the RSIA and described above.

1.4 Scope

The research described in this report used the data and results from previous studies of groups of railroad employees. The primary sources of data were the results of field surveys to gather work schedule and sleep data from the following groups of railroad employees: signalmen, MOW workers, dispatchers, T&E workers. Accident data and associated work schedules are also used to discuss the risk or probability of human factor accidents at various levels of fatigue. Neither the earlier studies nor this one attempted to characterize employees working for specific railroads. While the earlier studies focused on specific types of railroad jobs, this research combined data where appropriate, and compared and contrasted the characteristics of the groups.

1.5 Organization of the report

The report is organized around the current view that fatigue is largely a function of sleep and circadian rhythms. Sleep, in turn, is a function of work schedules. Work duration, TOD of work, and schedule variability are aspects of work schedules that determine when sleep can occur. Fatigue exposure is determined largely by work schedules, and fatigue exposure determines fatigue risk and the probability of human factor accidents. Section 2 describes the nature of the various railroad jobs and their work schedules. This section also includes a brief overview of the study methodology used to collect work and sleep data. Section 3 discusses and compares the sleep patterns of the various groups. The use of fatigue prediction models to estimate fatigue exposure in various railroad groups is the focus of Section 4, and Section 5 discusses the relationship between fatigue and the risk of railroad accidents. Section 6 presents key findings and suggests some future directions for fatigue research and fatigue risk management in the railroad industry.

2. Work Schedules

As noted previously, fatigue is a function of sleep and circadian rhythms. Work schedules have a significant influence on many sleep characteristics such as duration of sleep, TOD of sleep (a circadian factor), and number of sleep periods in a day. The objective of all the diary studies was to characterize the work schedules and sleep patterns of railroad employees involved in the safe movement of trains. Achieving this objective required a series of nationwide surveys using a similar methodology so that results could be compared. This section describes the nature of the work of each group and the methodology used for the diary studies. It also discusses the nature of the U.S. railroad industry's work schedules.

2.1 Nature of Railroad Jobs

Railroading is often said to be a round-the-clock, 7-days-a-week operation. Because operating and maintaining the Nation's railroads requires a wide array of workers, many employees who perform safety critical jobs are subject to fatigue. Of particular concern are signalmen, MOW workers, dispatchers, and T&E crews. The subsections below discuss the nature of each of those jobs and the associated types of work schedules. Table 1 provides an overview of the work schedules. The subsections below provide further explanation of the schedules. The HOS Law covers all but MOW workers. Consequently, MOW workers become a natural control group for any future study of the effectiveness of regulations implemented after passage of the RSIA. Signalmen and MOW workers work primarily during daytime while dispatchers and T&E employees work round-the-clock. Extra board dispatchers, most road freight crews, and extra board T&E in passenger service do not have fixed start times while the other jobs do.

Table 1. Types of Work Schedules by Group

Employee Group	Covered by HOS Law?	Work Schedules
Signalmen	Yes	Daytime – 4 or 5 d per week or 8 d on/6 d off
MOW Workers	No	Daytime – 4 or 5 d per week or 8 d on/6 d off
Dispatchers	Yes – trick No – chief	Shift workers – 1st, 2nd, 3rd, relief, extra board
Train and Engine Service	Yes	Yard jobs – fixed start, extra board Commuter/passenger – straight through, split, extra board Road freight – fixed and variable start

2.1.1 Signalmen

Signalmen work two fundamental types of jobs: maintenance and construction. Signal maintainers are responsible for inspecting and certifying the functioning of the signal and communication equipment on a specific track territory. The maintainer is also responsible for making minor repairs as he/she inspects. Depending upon the railroad, a separate gang of maintainers may be responsible for repairs that cannot be done in the course of the routine inspection. The job of a maintainer has a regular daily schedule of 4 or 5 d per week, but the maintainer is also subject to call for emergencies at night and on weekends. Major yards also have maintainers permanently assigned to maintain the signal system in the yard. These individuals work on a shift work schedule to cover the yard around the clock. Most signalmen work on wayside signal equipment, but a limited number work on communications equipment such as radios and antenna systems.

In contrast to the maintainer, a signalman who works on a construction gang will usually work a compressed schedule of 8 workdays followed by 6 d off, for example, and is rarely called for an emergency. Maintainers work in a defined geographic area. In contrast, signalmen on a construction gang can work anywhere on the railroad's system and likely travel long distances, on their own time, to reach the construction sites.

Signal maintainers are responsible for responding to emergencies at night and on weekends. Depending upon the nature of the territory, signal maintainers may have an on-call schedule, but more commonly they are responsible for all emergencies in their territory. When an emergency call comes, if the signalman has not worked 12 h, he/she may report back to work to handle the emergency.

Since 1976 the HOS Law for railroad workers and the associated FRA regulations (49 C.F.R. § 228) have applied to a railroad employee "engaged in installing, repairing or maintaining signal systems."

2.1.2 MOW Workers

MOW workers build and maintain the tracks, bridges, buildings, and other structures on the railroad. MOW work has two fundamental job classifications: production and nonproduction. Production jobs involve either track or bridge and building construction, while nonproduction jobs involve the inspection, maintenance, and repair of the same infrastructure. The nonproduction MOW worker is responsible for inspecting and certifying the condition of the right-of-way in a specific territory and initiating repairs or other remedial action when he/she finds defects. Nonproduction workers typically work either a 4-day or 5-day week, and they often support the work of production crews when on their territory. Nonproduction workers are also subject to calls to handle emergency problems at night and on rest days. Railroads typically assign nonproduction workers to a specific geographic area, which may encompass several hundred miles end-to-end.

In contrast to the nonproduction jobs, a MOW worker on a production gang will frequently work a compressed schedule of 8 workdays followed by 6 or 7 d off, for example, and is rarely called for an emergency. The industry frequently refers to this type of schedule as compressed halves. The railroad may assign its production workers to any location on the railroad's system, and, as such, these workers, like signalmen on a construction gang, must often travel long distances on their own time to reach the lodging site or rally point for the construction project.

Most construction work occurs during months of good weather, especially in the colder climate areas of the country, while nonproduction inspection and maintenance is done year round. Cold weather and snow lead to increased track maintenance problems during the winter months. This increased winter workload can result in long workdays and emergency calls at night and on rest days.

Unlike the operating crafts (i.e., train and engine crews) and signalmen, no statutory limits exist on the number of hours that MOW workers may work. A few railroads have taken voluntary steps to reduce fatigue by limiting work hours, but this is the exception rather than the norm.

2.1.3 Dispatchers

The railroad dispatcher is responsible for the safe, efficient, and economical movement of trains and other railway vehicles over the railroad, as well as for the protection of those who work on the railroad. The job requires the dispatcher to issue, monitor, and cancel track usage authorizations in accordance with the railroad's operating rules and procedures. The dispatcher also operates signals, switches, and bridges; communicates with train and MOW crews; responds to emergency events; and performs administrative and clerical duties. Every dispatcher is responsible for a predefined territory or portion of the railroad's network.

With few exceptions, today's dispatchers work with computer-based dispatching and communications technology. Dispatchers for the larger Class I railroads work in shifts around the clock in large centralized operations.[5] Upwards of 100 dispatchers may work the same shift in a large centralized operations center. Some may control territories that are located over 1,000 miles away. As the cost of computer systems decreases, even the smaller railroads are abandoning paper forms and radio directives in favor of the computer-based dispatching technology.

To meet the need for 24-hour operation, railroads staff their dispatching center with three 8-hour shifts. Typical shifts are 7 a.m. to 3 p.m. (day), 3 p.m. to 11 p.m. (evening), and 11 p.m. to 7 a.m. (night). Three categories of jobs exist in all dispatching centers: regular jobs, relief jobs, and extra board jobs. Regular jobs work 5 consecutive d on the same shift followed by 2 consecutive d off. Relief jobs work 5 consecutive d by rotating through the shifts, in a pattern such as 2 d, 2 evenings, and 1 night. Occasionally, a relief job will work the same shift each day but will not be responsible for the same territory each day. While the regular and relief jobs work the same days each week, the extra board jobs do not have a fixed schedule. The extra board dispatchers fill in for regular and relief dispatchers during vacations, training, and road days, as well as when an unplanned absence occurs. On occasion, a regular dispatcher on a rest day may fill a vacancy if an extra board dispatcher is not available. Most dispatching centers have a guaranteed extra board. This means that the extra board dispatchers are guaranteed 5 d of work per week, but the days and shifts that they work may change weekly. In addition, extra board dispatchers usually do not have 2 consecutive rest days.

All dispatching centers have a chief dispatcher who oversees the entire dispatching operation. In larger centers, assistant chief dispatchers supervise groups of trick dispatchers. (A trick dispatcher works as described above. The term "dispatcher" may refer to an assistant chief or a trick dispatcher.) The chief and/or the assistant chief provide backup support to the trick dispatchers as required. Like the majority of trick dispatchers, the chief and assistant chief positions have an assigned shift. Some assistant chiefs work a relief schedule that involves a rotating shift pattern. No extra board exists specifically for assistant chief positions. When a

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[5] The Surface Transportation Board currently defines a Class 1 railroad as one with revenues exceeding $398.7 million. There are eight Class I railroads in the U.S.

vacancy occurs in an assistant chief position, a trick dispatcher or other assistant chief who is qualified to work the open position will fill in.

As is the case with train and engine crews and signalmen, the HOS Law limits the length of the dispatcher's workday. The dispatcher may not remain on duty for more than 9 h, whether consecutive or in the aggregate, in any 24-hour period, in operations that employ two or more shifts. This means that once the dispatcher has worked for 9 h, he/she must have 15 h of rest. Where only one shift is employed, the dispatcher may remain on duty up to 12 h in any 24-hour period. During an emergency situation, the law allows the dispatcher to remain on duty for an additional 4 h in any 24-hour period for a maximum of 3 d over the course of 7 d. The law limits the length of the dispatcher's shift and provides for guaranteed time off, but it does not address the number of consecutive days that the dispatcher may work. Because chiefs and assistant chiefs are typically not directly responsible for overseeing train movements, the HOS Law does not apply to these positions. As a result, individuals in these positions may sometimes work for 12 or 16 h to cover a vacancy.

2.1.4 Train and Engine Service

T&E employees are the largest group of employees on a railroad. They operate the trains both between terminals and in railroad yard environments. There are several types of T&E work. *Road freight* work involves moving trains over long distances between major terminals or interchange points and frequently requires overnight stays at an out-of-town location. In contrast, *local freight* involves moving trains between a railroad yard and a nearby location, and the employee returns to the starting location at the end of the work period. T&E employees who work in *passenger or commuter operations* usually return to their starting location, but some who work in intercity service may be required to stay at an out-of-town location. Work in a *railroad yard* involves breaking up inbound trains, identifying freight for local delivery, and making up trains of outbound freight.

The work schedule of T&E employees may have either a regular start time or one that varies unpredictably from day to day. Most yard operations, local freight service, and passenger and commuter operations have jobs with regular start times. Employees on the extra board—in yard and road freight operations, as well as passenger service—fill in for regularly assigned T&E workers and as such their work schedule may vary from day to day. Because most yards operate 24 h a day, railroads staff their yards with either three 8-hour shifts or two 12-hour shifts. Jobs in passenger service may involve a split assignment where the individual works the morning rush, has time off in the middle of the day, and returns to work the evening rush. The period of time between the two work periods is often referred to as "interim release." During this period, the employee is off duty but must be available to work if called. If the interim release occurs at a location other than the employee's reporting point, the railroad must provide a quiet room or other facility where the employee may rest. If the interim release period is less than 4 h, it will count as on-duty time in terms of the HOS Law, so there is a disincentive for the railroad to limit the time between the two work periods. The end result is that the time the employee has before and after work for personal activities and sleep becomes limited.

T&E workers in road freight service do not have a regular work schedule in terms of either the days that they work or the time that they must report for work. A limited number of collective bargaining agreements have provisions for guaranteed rest days. This situation makes it difficult for the T&E worker to plan his/her sleep and personal activities. The recent changes in the HOS

Law and subsequent FRA regulations requiring a period of undisturbed rest have improved the situation as it existed when the T&E surveys were conducted.

Other situations compromise the start of the rest period. When the T&E worker in road freight service reaches the 12-hour limit of the on-duty period, the employee's rest period may not begin immediately. Frequently a crew reaches this limit, but they have not yet arrived at their destination. When this occurs, they must wait for a relief crew or transportation to the final destination. Sometimes this situation creates the opportunity for a nap depending on railroad policy. This period of time is referred to as limbo time, meaning that it is neither on-duty time nor rest period. Another circumstance that can postpone the start of the rest period involves deadheading (e.g., ride as passengers, not crew, on another road freight train or in other transportation) back to the home terminal. When the crew arrives at the destination terminal, regardless of whether or not they have reached the statutory 12-hour limit, they may be asked to deadhead back to their home terminal. In this situation, the deadhead time is considered limbo time, thus postponing the start of the rest period. Once again, the crew may be able to nap on the return to the home terminal.

2.2 Overall Survey Study Methodology

Each of the five survey studies used the same overall approach described below. The field survey projects consisted of three phases: preparation, field data collection, and data analysis. The preparation phase involved designing the survey methodology and procedures, conducting a pilot survey to refine the survey instruments and data collection procedure, securing approval from the Office of Management and Budget (OMB), and preparing the final survey instruments. (Because each survey involved more than nine participants, Federal regulations required that OMB approve the overall study design.) Activities during this phase included discussions with labor representatives to assure that the survey instruments had suitable wording and would collect the data necessary to address the research issues. A pilot survey, conducted concurrently with the OMB review process, confirmed that the survey would capture the data needed to meet the survey objectives.

The second phase of the research consisted of distributing the survey materials and collecting the survey data. Analysis of the survey data was the final phase. A nonresponse bias study validated that no difference existed between the survey participants and the nonrespondents. For all surveys, age was the basis for the nonresponse bias analysis.[6] The data analysis methods for the survey data included descriptive statistics, analysis of variance (ANOVA), and textual analysis of the logbook comments.

The potential respondent universe for each study consisted of the actively working members of the unions representing the employee group. A random sample of the potential respondents was drawn. The size of the potential respondent universe, acceptable error tolerance, and desired reliability of the results determined the sample size.

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[6] OMB requires that a nonresponse bias study be conducted if the survey response rate is below 75 percent. The purpose of the nonresponse bias study is to assure that no difference exists in the characteristics of the survey respondents versus the nonresponents. Age was a characteristic available for use in each group to test for differences.

Each person in the random sample received two study instruments, a background survey and a daily activity and sleep log. Survey participants used the background survey to provide demographic information; descriptive data for their type of work, type of position, and work schedule; and a self-assessment of overall health. The daily log provided the means for survey participants to record their daily activities in terms of sleep, personal time, commute to/from work, and work time. They also provided self-assessments of the quality of their sleep and their level of alertness at the start and end of each work period. Table 2 provides the overall response rates for each survey.

Table 2. Survey Response Rates

Group	**Response Rate**
Signalmen	49.9%
MOW	31.0%
Dispatchers	46.0%
T&E	32.8%
Passenger T&E	21.1%

2.3 Nature of Work Schedules

The background survey provided information on the participant's nominal work schedule so that researchers could characterize it. The types of schedules varied by group as indicated in Table 1. The data from the daily logs was analyzed to characterize actual work. Nominal and actual work differ due to overtime and, for signalmen and MOW workers, emergency calls outside of normal work periods.

2.3.1 Work Periods

Both signal and MOW jobs start in the early morning, have a guaranteed meal break of 30 min, and end between 3 and 6 p.m. Nearly all MOW jobs start between 5 and 8 a.m. while signal jobs tend to start between 6 and 8 a.m. This is true for both construction/production jobs and nonconstruction/nonproduction jobs. Table 3 provides the median start and end times for these jobs along with their work time over the 2-week observation period. The nonconstruction signal jobs reported the most instances of callbacks for emergencies; therefore, their work in 2 weeks included more than 5 h of overtime. Production and nonproduction MOW worked similar amounts of overtime.

Table 3. Work Periods of Signalmen and MOW Workers

	Signalmen		MOW	
	Construction	Non-Construction	Production	Non-Production
Start Time (median)	7 a.m.	7 a.m.	6:35 a.m.	6:50 a.m.
End Time (median)	5 p.m.	4 p.m.	5 p.m.	4 p.m.
Work in 2 weeks (median, h:min)	80:00	85:25	84:30	83:39
Meal Break	30 min	30 min	30 min	30 min

Because dispatchers are shift workers, their start times cluster around three time periods: 6–7 a.m., 2–3 p.m., and 10–11 p.m. Trick dispatchers work regular 8 h shifts. Overtime for them is an additional shift on a planned rest day. Assistant chief dispatchers work a similar schedule but because their work hours are frequently not limited by HOS, they may work a longer shift. Their work in 2 weeks, as shown in Table 4, indicates more than 5½ h of overtime. Dispatchers do not have guaranteed breaks, but they are frequently able to get away from their desks for short periods. Trick dispatchers have more breaks than assistant chiefs but their breaks tend to be shorter.

Table 4. Work Time and Breaks for Dispatchers

	Job type	
	Trick Dispatcher	Assistant Chief
Work in 2 weeks (median, h:min)	80:25	85:33
Number of Breaks	2	1
Length of Longest Break	7 min	10 min

The schedules of T&E workers, unlike signalmen, MOW workers, and dispatchers, may have a fixed or variable start time. In passenger service, both the straight through and split assignment jobs have a regular start time. In the case of split assignments, there are actually two start times (one for each segment of the job). Most road freight jobs do not have a regular start time, and in this respect, they are like the extra board jobs in passenger service. The distribution of work start and end times for T&E is not as heavily clustered around specific times as is the case with the other jobs discussed above. More than 80 percent of signal and MOW jobs start between 6 and 8 a.m., but only 17 percent of T&E jobs start at this time. Table 5 provides the median work in 2 weeks and the median daily duty hours for each T&E schedule group. The fixed start T&E

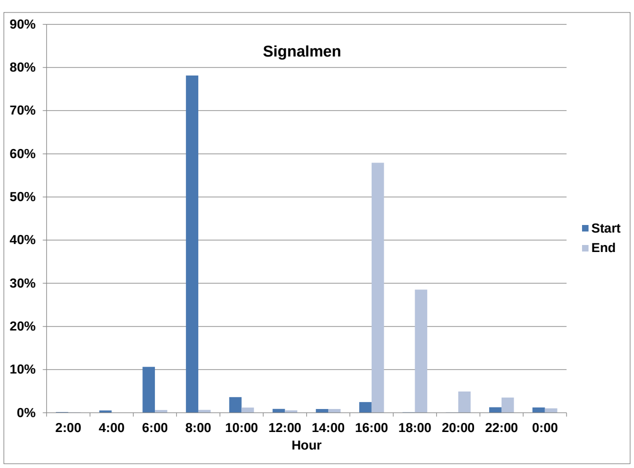
workers and passenger T&E on straight through assignments worked the most hours of all of the groups surveyed.

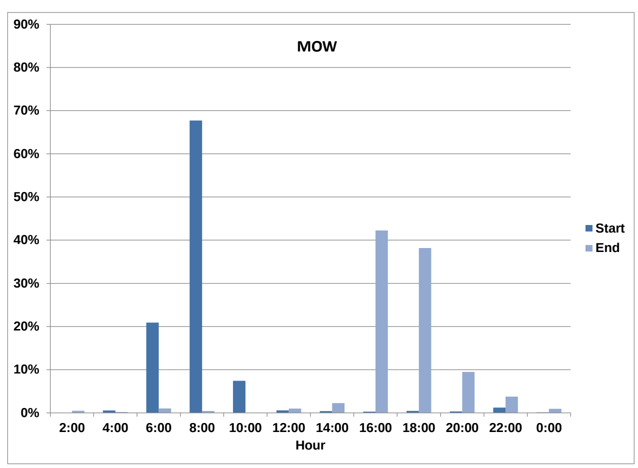
Table 5. Work Periods for T&E (h:min)

	All T&E		Passenger T&E		
	Fixed Start	**Variable Start**	**Straight thru**	**Split**	**Extra board**
Work in 2 weeks (median, h:min)	86:17	84:12	89:20	77:10	81:05
Daily Duty Hours (median)	8:42	8:39	8:46	8:08	8:35

Average duration of work in 2 weeks across the groups did not show much variation. Passenger T&E worked 82:31, signalmen worked 82:43, dispatchers worked 82:59, MOW worked 84:04, and T&E worked 85:15.

Figure 2 contains distributions of the work start and end times for each of the groups. As these graphs illustrate, signalmen and MOW workers have similar schedules. Both T&E and Passenger T&E have work starts and ends spread throughout the day with Passenger T&E having more work starts during daytime. The graph for the dispatchers illustrates the three distinct shifts. A χ^2 analysis of the start and end times for each of the five groups confirmed that none of them follow a uniform distribution; all had $p < 0.05$. This means that there are definite highs and lows to the work starts and ends throughout the day. Railroading is a round-the-clock, 7-days-a-week operation, but operations are not uniform throughout the day. The groups with schedules that would most likely be at risk for fatigue because of circadian influences on sleep and work are the T&E, passenger T&E, and dispatchers.





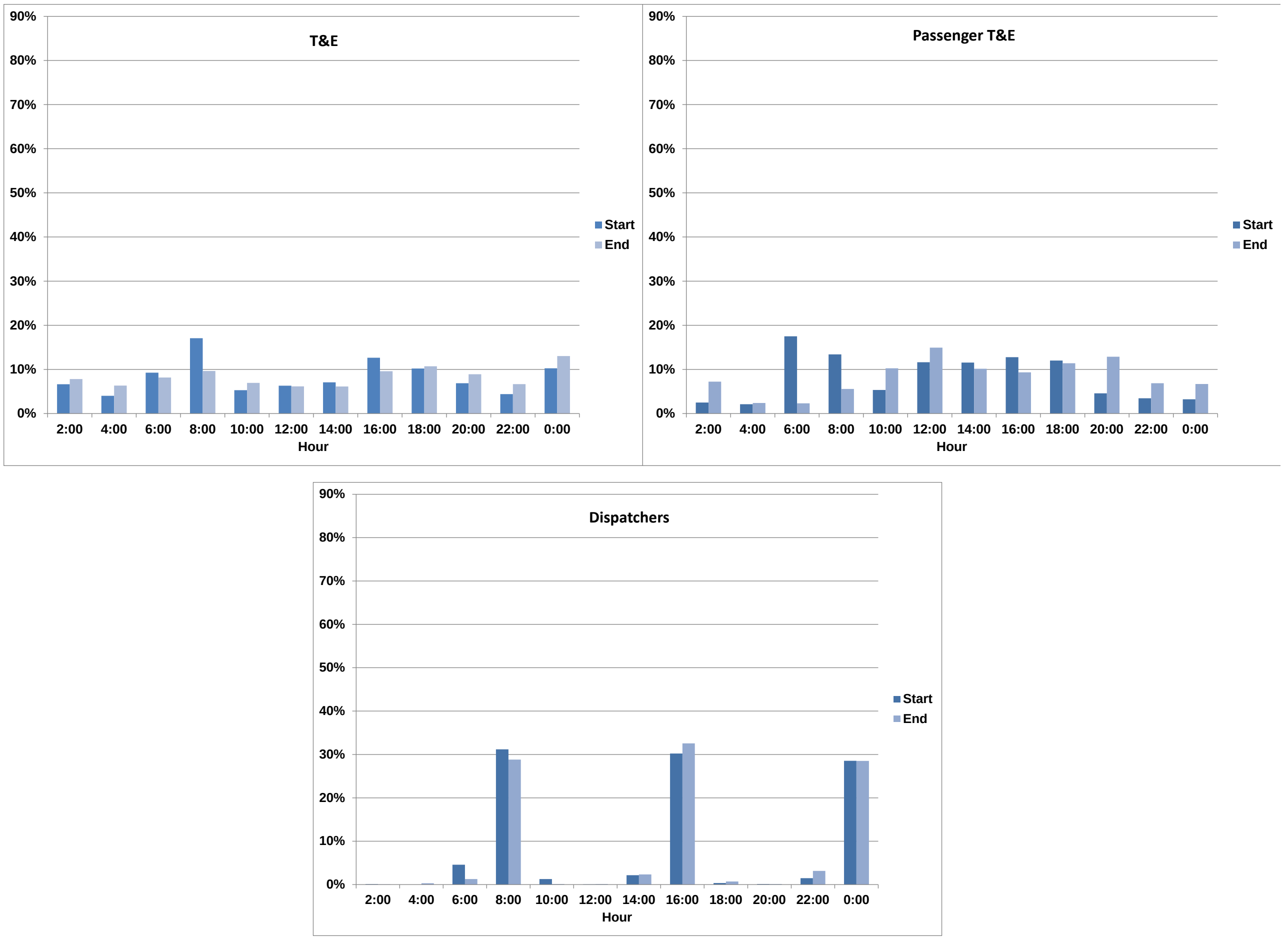


Figure 2. Work Start and End Times by Group

The RSIA limits total time on duty for T&E to 276 h in 30 d. While these restrictions were not in place at the time of the surveys, the survey data allows projection of the impact that this regulation might have on all of the groups. By extrapolating the 14 d of survey data to 30 d, it is possible to estimate the number of railroad workers who likely exceeded the RSIA limit during the study period. Table 6 presents the results of this analysis, which indicates that the T&E workers were most likely to exceed the 276-hour limit; this is in fact the group subject to the new limitation.

Table 6. Potential Compliance with the RSIA Cumulative Work Hour Limit

Group	Number (%) >276 h	Hours Worked in 30 Days: Mean	Standard Deviation	Median
Signalmen	3 (0.79)	185	29.4	184
MOW	1 (0.42)	181	28.0	180
Dispatchers	3 (0.69)	175	23.6	172
T&E	12 (5.17)	190	48.7	185
Passenger T&E	3 (1.25)	186	42.2	187

2.3.2 Schedule Variability

Schedule variability is a concern because it can lead to fatigue if it disrupts the worker's normal sleep pattern. Each of the prior studies examined schedule variability in terms of start time variability. A change in start time of more than 1 h from the previous day was the definition for start time variability.

For the signalmen, 10 percent of construction signalmen and 37 percent of nonconstruction signalmen had one or more instances of start time variability during the 2-week period of the study. The relationship between start time variability and job type was statistically significant—χ^2 (4, N = 389) = 26.93, p < 0.05—indicating that start time variability is not independent of job type. The higher level of variability in nonconstruction signalmen's schedules was likely due to the need to respond to emergencies.

Start time variability for MOW workers was similar to start time variability for signalmen. Sixteen percent of production MOW workers had at least one instance of start time variability, and 22 percent of nonproduction MOW workers experienced start time variability at least once. This difference between job types was not statistically significant, χ^2 (4, N = 254) = 5.21, p = 0.267.

For dispatchers, schedule variability applies to only those working relief jobs and the extra board. Nearly 70 percent of the participants in the dispatcher study worked the same shift each day. The remainder was split between relief (19 percent) and extra board (12 percent). The most common shift rotation for relief dispatchers was two first shifts, two second shifts, and then one third shift. HOS regulations do not permit backward rotation.

Start time variability in the T&E study was examined in terms of difference in start time from the prior work period. T&E, as a group, experiences the greatest amount of start time variability, and this has been a major contributor to their fatigue issues. Even those working jobs with a fixed start time had a mean start time variability of 3.3 h. T&E workers on jobs with variable start times had a mean start time variability of 7.1 h, and a quarter of these jobs had a start time variability of nearly 9 h or more. (The analysis considered mean start time variability, rather than number of work starts varying more than 1 h, so that the results could be compared with an earlier GAO study.)

There was little schedule variability for the T&E workers in passenger service; therefore, as with the dispatchers, schedule variability analysis was not meaningful.

2.4 Summary

Work schedules have a significant influence on several aspects of sleep and are important for understanding fatigue in any work group. The work schedules of signalmen, MOW, dispatchers, T&E, and passenger T&E differ mainly in the TOD of work and the variability of the work schedules. Both of these are factors that could affect opportunities to sleep, the ability to sleep, and alertness at work. Duration of work varies in a 2-week period by less than 3 h on the average and is probably not an important factor in discerning differences in fatigue among the groups studied.

3. Sleep Patterns

This section characterizes the sleep patterns of each railroad work group, as well as the quality of sleep as it was subjectively self-reported in the surveys. This is the first comprehensive look at sleep characteristics in the U.S. railroad industry as a factor in determining fatigue exposure and risk. Because opportunities to sleep and ability to sleep are highly influenced by work schedule, sleep among all work groups is contrasted by the type of schedule respondents within each group reported. Also, the sleep of each work group is compared with the sleep of U.S. working adults. This section describes the incidence of sleep disorders in the industry, as well as the exposure of workers to fatigue education. The section concludes with a characterization of the subjective alertness of the various work groups.

3.1 Sleep Analysis by Work Schedule and Type of Day

Because railroad work schedules must accommodate round-the-clock, 7-days-a-week operations, employee sleep schedules vary accordingly. Sometimes these schedules are at odds with the circadian cycle that governs human sleep and alertness. Therefore, work schedules are a major determinant of when people will sleep and the length as well as the quality of their sleep. Humans are better adapted to work schedules that allow for regular and adequate amounts of nighttime sleep. As work schedules interrupt this natural diurnal pattern by shifting the onset of sleep to a less optimal time, reducing the required amount of sleep, or excessively segmenting sleep, the risk of fatigue and a decline in alertness ensue.

Given that work schedules largely determine employees' opportunity to sleep, the analysis of sleep as it varies by type of work schedule—on both work and rest days—is of interest. In previous reports of these data, sleep was analyzed using slightly different methods (Gertler and DiFiore, 2009, 2011; Gertler and Viale, 2006a, 2006b, 2007). The following describes a re-examination of railroad employee sleep data using consistent metrics and analysis methods to facilitate comparisons across work groups. This factorial analysis examines three basic sleep metrics: daily primary sleep length, total daily sleep length, and the average number of daily sleep periods.

For the purpose of the analysis, daily primary sleep for a given calendar day is the longest sleep period ending on that day. Daily primary sleep provides limited information about an individual's sleep on a calendar day. Total daily sleep—that is, primary plus any supplementary sleep periods—provides a more complete measure of sleep. Total daily sleep is the sum of all sleep periods that end on a calendar day. Since workday and rest day sleep may differ, it is important to characterize average total daily sleep for employees on both workdays and rest days to determine the overall pattern of supplementary sleep. Each sleep period ending on a calendar day is counted to determine the number of sleep periods per day. The average number of daily sleep periods is an important metric that determines the extent to which an employee's sleep is segmented, which can result in fatigue if sleep periods are not sufficient to allow individuals to cycle through the typical stages of sleep.

Table 7 shows the types of schedules included in the work group analyses. Each subsection below examines sleep by the type of work group. However, the last subsection combines similar types of schedules across work groups to examine the aforementioned sleep metrics. The subsections also examine sleep patterns as they vary by the type of day. The authors define workdays and rest days with the following operational definitions. Workdays have at least one work start time reported in a calendar day. By contrast, rest days have no work starts occurring during a calendar day. If a sleep period ends on a workday, it is classified as workday sleep. Otherwise, if a sleep period ends on a rest day, it is considered rest day sleep. Understanding the method for categorizing sleep as workday or rest day sleep is important when reviewing the following results. All sleep metrics were averaged for each individual respondent.

Table 7. Work Schedules for Employee Groups

Employee Group	Work Schedules
Signalmen	4 or 5 days per week or 8 on/6 off
MOW Workers	4 or 5 days per week or 8 on/6 off
Dispatchers	1st shift, 2nd shift, 3rd shift, relief, extra board
T&E	Fixed start time, variable start time, extra board
Passenger T&E	Straight through assignment, Split assignment, extra board

3.1.1 Signalmen

Table 8 presents descriptive statistics for daily primary sleep, total daily sleep, and the average number of sleep periods per day by type of schedule (4-day, 5-day and 8 on/6 off) and type of day (work or rest).

Table 8. Signalmen Sleep by Type of Day and Work Schedule (h)

	4-day Assignment				5-day Assignment				8 days on/6 days off			
			95% CI				95% CI				95% CI	
	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper
	Daily Primary Sleep											
Workday	6.64	0.12	6.41	6.88	6.54	0.06	6.43	6.65	6.57	0.18	6.22	6.92
Rest day	7.77	0.13	7.50	8.03	7.23	0.07	7.09	7.36	7.66	0.21	7.26	8.07
	Total Daily Sleep											
Workday	6.72	0.09	6.54	6.90	6.80	0.04	6.72	6.88	6.75	0.13	6.49	7.02
Rest day	8.06	0.10	7.86	8.27	7.78	0.05	7.67	7.88	7.85	0.16	7.54	8.16
	Daily Sleep Periods											
Workday	1.02	0.03	0.97	1.07	1.12	0.01	1.10	1.15	1.10	0.04	1.03	1.18
Rest day	1.04	0.03	0.99	1.10	1.07	0.01	1.04	1.09	1.10	0.04	1.02	1.18

CI = Confidence Interval

A 2 (type of day) x 3 (schedule) ANOVA examined the average length of daily primary sleep for each respondent. The results indicate differences in the length of daily primary sleep among individuals working 4-day, 5-day, or 8 on/6 off work schedules, $F(2, 382) = 3.55$, $p < 0.05$.

Signalmen working a 5-day schedule report less primary sleep ($\bar{x}$ = 6.88 h) than those working 4-day ($\bar{x}$ = 7.20 h) or 8 on/6 off ($\bar{x}$ = 7.12 h) work schedules. The length of primary sleep is significantly longer on rest days than on workdays, $F(1, 382) = 214.44$, $p < 0.0001$, suggesting that signalmen make up sleep on their days off. A significant interaction exists between type of schedule and day, $F(2, 382) = 8.79$, $p < 0.001$. Essentially, 5-day workers have less difference in the length of daily primary sleep between work and rest days than the signalmen working other types of schedules. Figure 3 shows daily primary sleep by the type of schedule worked and the relative work and rest day amounts of primary sleep.

Figure 3. Daily Primary Sleep for Signalmen by Schedule and Type of Day

A 2 (type of day) x 3 (schedule) ANOVA also examined the average length of total daily sleep for each respondent. The results indicate no significant differences in the length of total daily sleep among individuals working 4-day, 5-day or 8 on/6 off work schedules, $F(2, 382) = .57$, $p = 0.56$. These findings demonstrate that signalmen working a 5-day schedule are able to obtain comparable amounts of total daily sleep with supplementary sleep periods. The length of total daily sleep is also significantly longer on rest days than on workdays, $F(1, 382) = 464.87$, $p < 0.0001$. For total daily sleep, a significant interaction exists between type of schedule and day, $F(2, 382) = 7.4$, $p < 0.001$. The nature of this interaction is the same as the previous interaction reported for daily primary sleep; 5-day workers have less difference in the length of total daily sleep between work and rest days than signalmen working other types of schedules. Figure 4 shows total daily sleep by the type of schedule worked and the relative work and rest day amounts of total sleep.

An analysis of the average number of daily sleep periods for signalmen demonstrates how workers on a 5-day schedule supplement their sleep to obtain comparable total amounts of sleep with those working different schedules. A 2 (type of day) x 3 (schedule) ANOVA examined the average number of sleep periods per day. Overall, there were no significant differences among the different types of schedules, $F(1, 382) = 2.73$, $p = 0.07$, or type of day, $F(1, 382) = 0.89$, $p =$

0.35. However, there was a significant day by schedule interaction, $F(1, 382) = 4.98$, $p < 0.01$. Figure 5 illustrates the nature of this interaction.

The sleep patterns of signalmen show that, overall, they sleep more on rest days than on workdays. Although signalmen working a 5-day work schedule report less daily primary sleep than signalmen working other types of schedules, no significant differences exist among the three different types of schedules with respect to total daily sleep. This is due to the supplementary sleep strategy of 5-day workers. Five-day workers tend to supplement their sleep on workdays, whereas 4-day workers supplement their sleep on rest days and the 8 on/6 off group supplements their sleep equitably on work and rest days.

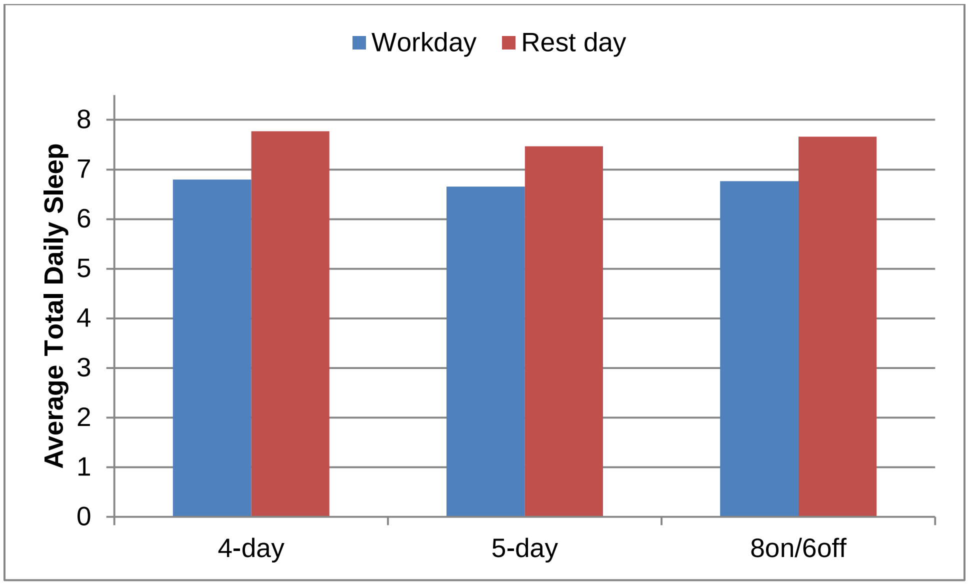


Figure 4. Total Daily Sleep for Signalmen by Schedule and Type of Day

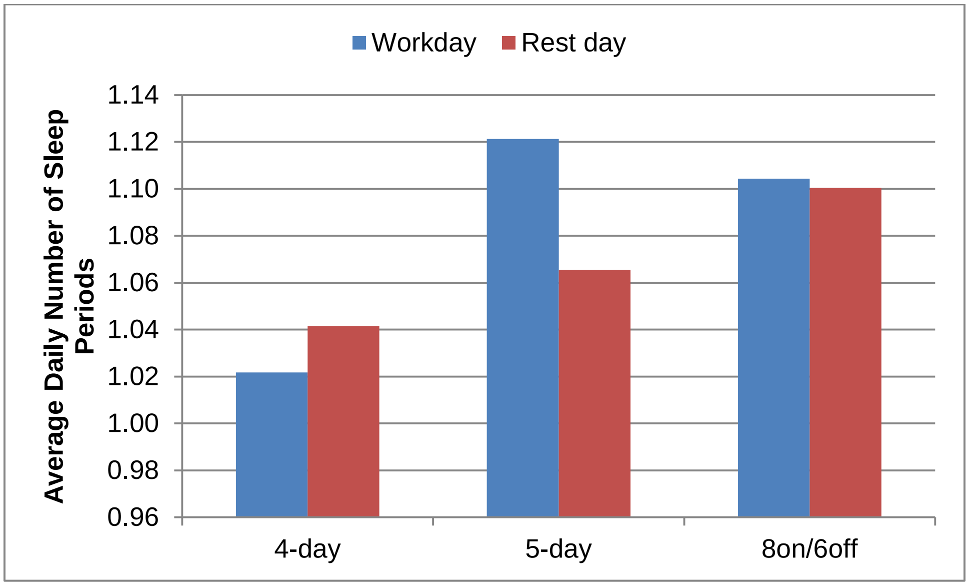


Figure 5. Signalmen Daily Sleep Periods by Schedule and Type of Day

3.1.2 Maintenance of Way Employees

Table 9 presents descriptive statistics for daily primary sleep, total daily sleep, and the average number of sleep periods per day by type of schedule (4-day, 5-day and 8 on/6 off) and type of day (work or rest).

The same analysis approach described above for signalmen sleep was used for MOW sleep. However, the only consistent statistical effect that emerged from the MOW analysis was that MOW workers reported larger amounts of sleep on rest days than on workdays. The effect was significant for both daily primary sleep and total daily sleep, $F(1, 244) = 204.45$, $p < 0.001$ and $F(1, 244) = 234.04$, $p < 0.0001$, respectively. MOW workers also reported significantly more sleep periods on rest days than on workdays regardless of schedule, $F(1, 242) = 15.52$, $p < 0.0001$. Figure 6 shows total daily sleep for MOW employees by schedule and type of day.

Table 9. MOW Sleep by Type of Day and Work Schedule (h)

	4-day Assignment				**5-day Assignment**				**8 days on/6 days off**			
			95% CI				**95% CI**				**95% CI**	
	Mean	**Std error**	**Lower**	**Upper**	**Mean**	**Std error**	**Lower**	**Upper**	**Mean**	**Std error**	**Lower**	**Upper**
	Daily Primary Sleep											
Workday	6.40	0.11	6.19	6.61	6.55	0.08	6.39	6.70	6.64	0.21	6.23	7.04
Rest day	7.36	0.12	7.12	7.61	7.42	0.10	7.23	7.62	7.73	0.21	7.31	8.15
	Total Daily Sleep											
Workday	6.48	0.11	6.27	6.70	6.59	0.08	6.43	6.75	6.68	0.21	6.27	7.10
Rest day	7.52	0.13	7.28	7.77	7.54	0.10	7.34	7.74	7.89	0.22	7.46	8.31
	Daily Sleep Periods											
Workday	1.08	0.02	1.04	1.13	1.03	0.02	1.00	1.07	1.03	0.04	0.95	1.12
Rest day	1.11	0.03	1.06	1.16	1.07	0.02	1.03	1.11	1.14	0.05	1.05	1.23

CI = Confidence Interval

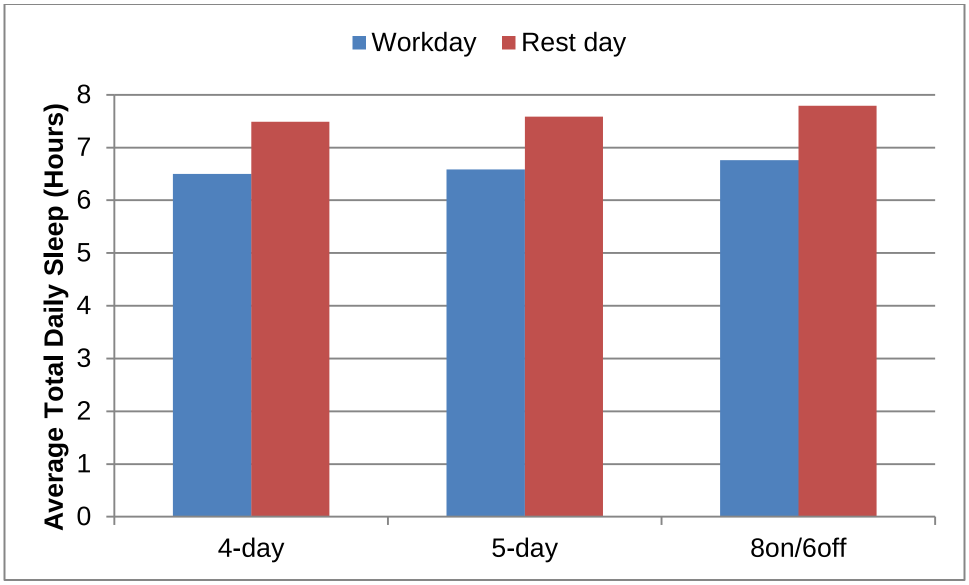


Figure 6. Total Daily Sleep for MOW Employees by Schedule and Type of Day

3.1.3 Dispatchers

Table 10 presents descriptive statistics for daily primary sleep, total daily sleep, and the average number of sleep periods per day by type of schedule (1st shift, 2nd shift, 3rd shift, relief, and extra board) and type of day (work or rest).

A 2 (type of day) x 5 (schedule) ANOVA examined the average length of primary sleep for each respondent. The results indicate that a statistically significant difference exists in the length of primary sleep among the different types of dispatcher schedules, $F(4, 438) = 24.38$, $p < 0.0001$. Third shift dispatchers obtained the least amount of primary sleep averaging only 5.81 h on workdays and 5.52 h on rest days. However, the length of primary sleep for this group of employees is not significantly different with regard to type of day—unlike what other railroad work groups reported, $F(1, 432) = 2.74$, $p = 0.10$. The schedule by day interaction was significant, $F(4, 432) = 38.17$, $p < 0.0001$. Figure 7 shows the nature of this interaction. Daily primary sleep was longer on rest days than workdays for first shift dispatchers. Conversely, workday primary sleep was longer than rest day primary sleep for both third shift dispatcher and relief employees. Second shift dispatchers and employees on the extra board obtained comparable amounts of daily primary sleep.

Table 10. Dispatcher Sleep by Type of Day and Work Schedule (h)

	1st Shift				2nd Shift				3rd Shift			
			95% CI				95% CI				95% CI	
	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper
	Daily Primary Sleep											
Workday	6.08	0.09	5.90	6.27	6.86	0.10	6.65	7.06	5.81	0.10	5.61	6.00
Rest day	7.25	0.12	7.02	7.49	6.96	0.13	6.71	7.22	5.52	0.13	5.27	5.77
	Total Daily Sleep											
Workday	6.40	0.09	6.23	6.56	7.09	0.09	6.91	7.27	6.87	0.09	6.69	7.05
Rest day	7.91	0.11	7.69	8.12	7.40	0.12	7.17	7.63	6.04	0.12	5.81	6.27
	Daily Sleep Periods											
Workday	1.19	0.03	1.14	1.24	1.16	0.03	1.10	1.22	1.41	0.03	1.36	1.47
Rest day	1.13	0.03	1.07	1.19	1.13	0.03	1.06	1.19	1.05	0.03	0.98	1.11

	Relief Assignment				Extra board Assignment			
			95% CI				95% CI	
	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper
	Daily primary sleep							
Workday	6.38	0.11	6.16	6.60	6.51	0.14	6.24	6.78
Rest day	5.73	0.14	5.45	6.01	6.62	0.17	6.29	6.95
	Total daily sleep							
Workday	6.98	0.10	6.79	7.18	6.96	0.12	6.72	7.20
Rest day	6.33	0.13	6.07	6.58	7.30	0.15	7.00	7.61
	Daily sleep periods							
Workday	1.34	0.03	1.28	1.40	1.21	0.04	1.14	1.29
Rest day	1.13	0.04	1.06	1.20	1.08	0.04	1.00	1.17

CI = Confidence Interval

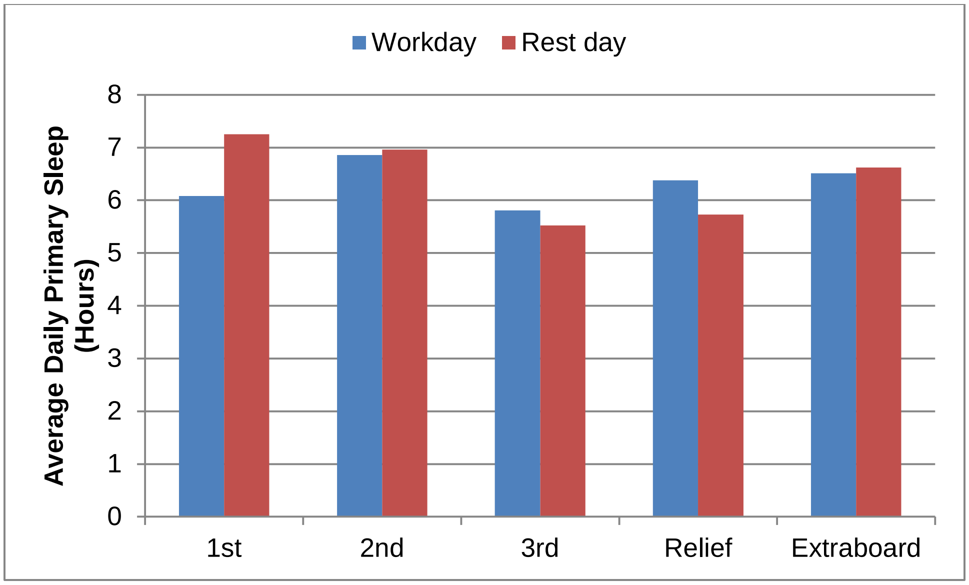


Figure 7. Daily Primary Sleep for Dispatchers by Schedule and Type of Day

A 2 (type of day) x 5 (schedule) ANOVA indicates a significant difference in the length of total daily sleep among the different types of dispatcher schedules, $F(4, 438) = 14.16$, $p < 0.0001$. The length of total daily sleep is also significantly longer on rest days than on workdays, $F(1, 421) = 7.13$, $p < 0.01$. For total daily sleep, a significant interaction exists between type of schedule and day, $F(4, 421) = 84.81$, $p < 0.0001$. Figure 8 shows dispatchers' total daily sleep by the type of schedule worked and the relative work and rest day amounts of total sleep. First shift, second shift, and extra board schedules report more total daily sleep on rest days than workdays; the opposite pattern exists with regard to third shift and relief dispatchers.

An analysis of dispatcher daily sleep periods shows that, overall, dispatchers report more sleep periods on workdays than on rest days $F(1, 432) = 142.66$, $p < 0.0001$. There was a marginal main effect for type of schedule, $F(4, 438) = 2.44$, $p = 0.05$, and a significant schedule by type of day interaction, $F(4, 432) = 23.22$, $p < 0.0001$. The latter effect exists because third shift dispatchers and relief workers have substantially more sleep periods on workdays than any of the other schedule types report on either workdays or rest days.

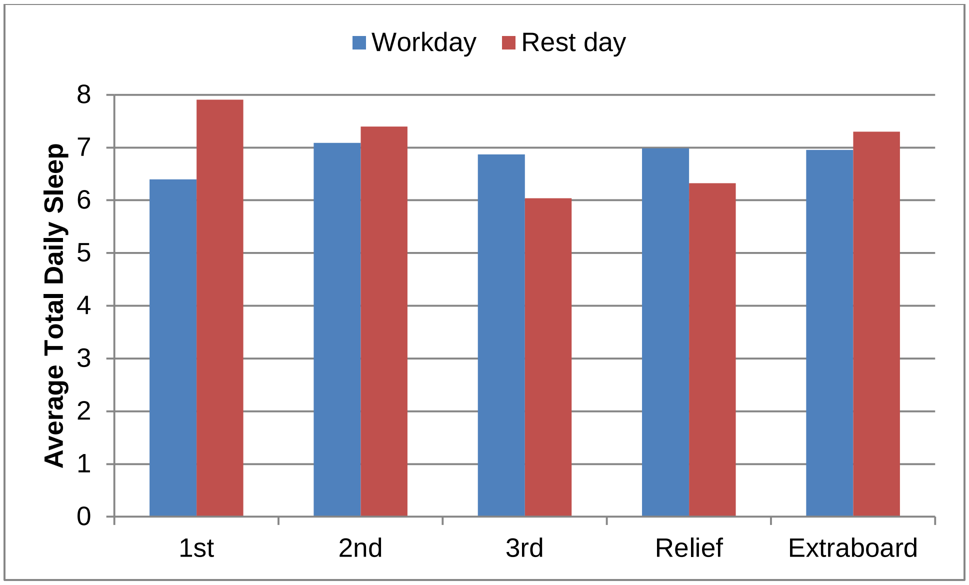


Figure 8. Total Daily Sleep for Dispatchers by Schedule and Type of Day

3.1.4 Train and Engine Service Employees

Table 11 presents descriptive statistics for daily primary sleep, total daily sleep, and the average number of sleep periods per day by type of schedule (fixed or variable start time) and type of day (work or rest).

A 2 (schedule) x 2 (type of day) ANOVA examined the average length of primary sleep for each respondent. The results indicate that, overall, no difference exists in the length of primary sleep between individuals working a fixed start schedule and those working a variable start time, $F(1, 248) = 0.59$, $p = 0.44$. However, the length of primary sleep is significantly longer on rest days than on workdays, $F(1, 244) = 61.03$, $p < 0.0001$, suggesting that T&E workers make up lost sleep on their days off. Also, a significant interaction exists between type of schedule and day, $F(1, 244) = 9.65$, $p < 0.01$.

A qualitative examination of the mean values of daily primary sleep by type of day, as shown in Figure 9, reveals that the source of this interaction is a trend for fixed start time workers to make up sleep on rest days to a larger extent than variable start time workers. With respect to workdays, fixed start time and variable start time workers obtain a similar amount of primary sleep. A potential explanation for these findings may be the schedule inconsistency of variable start time workers. Both unexpected calls to duty and start time variability prevent this group from dedicating specific time periods to long, uninterrupted sleep. Therefore, they may not be able to distinguish between work and rest days for the purpose of planning sleep.

Table 11. T&E Sleep by Type of Day and Work Schedule

	Fixed Start Time				Variable Start Time			
			95% CI				95% CI	
	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper
	Daily Primary Sleep							
Workday	6.83	0.10	6.62	7.03	6.98	0.07	6.84	7.13
Rest day	7.71	0.13	7.44	7.97	7.36	0.09	7.19	7.54
	Total Daily Sleep							
Workday	7.18	0.11	6.97	7.39	7.57	0.08	7.42	7.72
Rest day	8.10	0.14	7.83	8.38	7.90	0.09	7.73	8.08
	Daily Sleep Periods							
Workday	1.14	0.02	1.09	1.18	1.27	0.02	1.23	1.30
Rest day	1.16	0.03	1.10	1.22	1.24	0.02	1.20	1.28

CI = Confidence Interval

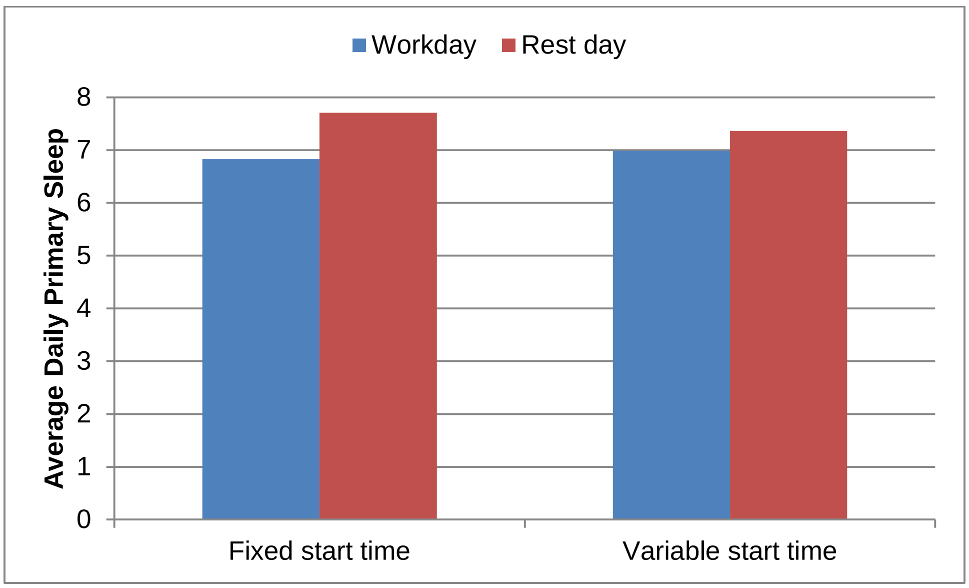


Figure 9. Daily Primary Sleep for T&E Employees by Schedule and Type of Day

A 2 (schedule) x 2 (type of day) ANOVA examined average total daily sleep and yielded a main effect for type of day, $F(1, 244) = 53.35$, $p < 0.0001$, and a significant interaction between schedule and type of day, $F(1, 244) = 11.85$, $p < 0.0001$. The main effect for schedule is not significant, $F(1, 248) = 0.61$, $p = 0.44$, suggesting that, overall, no difference in daily sleep exists between fixed and variable workers.

Examination of average daily sleep indicates that T&E workers sleep longer on rest days than on workdays; the results of the primary sleep period analysis also showed this pattern. This finding confirms that T&E workers as a group make up their sleep debt on their days off. Comparing fixed start and variable start workers' daily sleep on workdays and rest days yields different sleep trends for those days. Figure 10 presents the average total daily sleep by schedule and type of day. Variable start time workers log more daily sleep on workdays than fixed workers do. Fixed start time workers have longer daily sleep on rest days than variable start time workers—as is also the case with daily primary sleep. As mentioned previously, no statistically significant difference exists between primary sleep for the two groups on workdays; however, variable start time workers get more total daily sleep than fixed workers on those days. The results indicate that variable start time workers nap on workdays. Essentially, variable start time workers engage in supplementary sleep throughout the day.

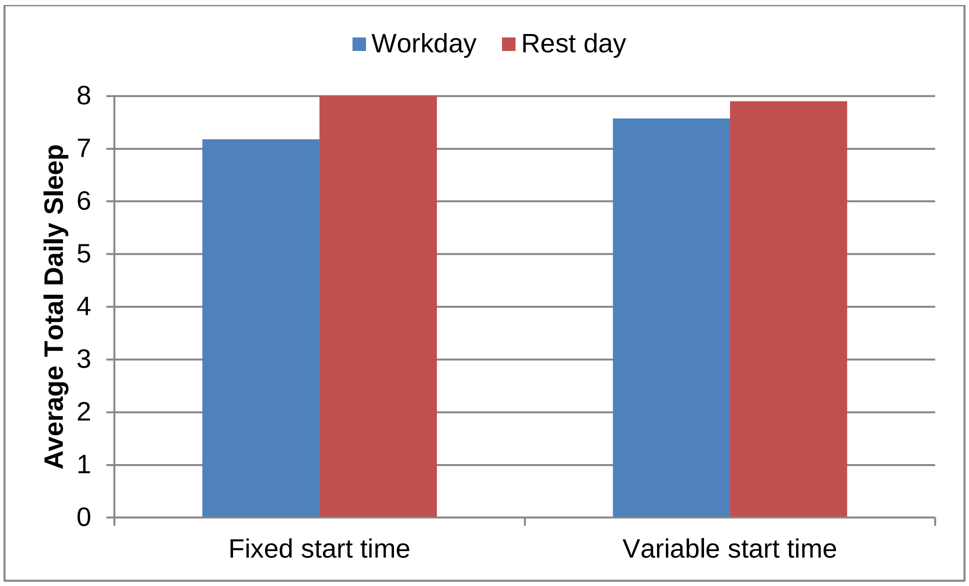


Figure 10. Total Daily Sleep for T&E Employees by Schedule and Type of Day

An analysis comparing fixed start time and variable start time workers' daily sleep periods supports the hypothesis that variable start time workers log more daily sleep (but not primary sleep) on workdays because they are engaging in supplementary sleep. A 2 (schedule) x 2 (type of day) ANOVA examined the average number of sleep periods per day and yielded a main effect for schedule, $F(1, 248) = 14.68$, $p < 0.0001$, but not for type of day, $F(1, 244) = 0.04$, $p = 0.84$. That is, the average number of sleep periods per day is significantly higher for variable start time workers than for fixed start time workers. There was no significant type of day by type of schedule interaction with regard to daily sleep periods, $F(1, 244) = 1.96$, $p = 0.16$. While T&E personnel obtain approximately the same amount of sleep regardless of schedule, these results show that variable start time workers must obtain supplementary sleep to achieve the same total amount of sleep.

3.1.5 Passenger Train and Engine Service Employees

Table 12 presents descriptive statistics for daily primary sleep, total daily sleep, and the average number of sleep periods per day by type of schedule and type of day (work or rest) for passenger service T&E employees.

The results of an examination of daily primary sleep using a 2 (type of day) × 3 (schedule) ANOVA showed an overall effect of schedule on daily primary sleep, $F(2, 253) = 3.1$, $p = 0.05$. The main effect of type of day on primary sleep demonstrated that primary sleep on rest days was longer than primary sleep on workdays, $F(1, 243) = 365.98$, $p < 0.0001$. The length of primary sleep on workdays and rest days varied based on the type of schedule, as evidenced by the significant interaction between the two factors, $F(2, 243) = 29.36$, $p < 0.0001$. Figure 11 shows a bar chart of the daily primary sleep means by schedule and type of day.

Table 12. Passenger T&E Sleep by Type of Day and Work Schedule

	Straight Through Assignment				Split Assignment				Extra Board Assignment			
			95% CI				95% CI				95% CI	
	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper	Mean	Std error	Lower	Upper
	Daily Primary Sleep											
Workday	6.84	0.07	6.70	6.98	6.11	0.14	5.82	6.39	6.91	0.15	6.62	7.20
Rest day	8.15	0.09	7.98	8.32	8.24	0.17	7.90	8.57	7.51	0.17	7.17	7.85
	Total Daily Sleep											
Workday	7.08	0.07	6.95	7.21	7.23	0.14	6.96	7.50	7.21	0.14	6.93	7.48
Rest day	8.38	0.08	8.21	8.55	8.43	0.17	8.10	8.76	7.80	0.17	7.48	8.13
	Daily Sleep Periods											
Workday	1.16	0.02	1.12	1.20	1.64	0.04	1.56	1.72	1.15	0.04	1.08	1.23
Rest day	1.10	0.02	1.06	1.14	1.10	0.04	1.02	1.17	1.11	0.04	1.02	1.19

CI = Confidence Interval

Figure 11. Daily Primary Sleep for Passenger T&E Employees by Schedule and Type of Day

A 2 (type of day) × 3 (schedule) ANOVA examined the average length of total daily sleep. Figure 12 shows a bar chart of these means by schedule and type of day. The results indicate no overall difference in daily sleep among the three schedule groups, $F(2, 253) = 1.55$, $p = 0.21$. The main effect for type of day was significant, $F(1, 243) = 206.3$, $p < 0.0001$, demonstrating that regardless of schedule, respondents slept more on rest days than workdays. There was a significant interaction between schedule and type of day, $F(2, 243) = 9.42$, $p < 0.001$, suggesting that the length of total daily sleep on workdays and rest days varied based on the type of schedule.

Figure 12. Total Daily Sleep for Passenger T&E Employees by Schedule and Type of Day

The fact that split assignment employees get comparable amounts of total daily sleep on workdays and rest days, but significantly less primary sleep on workdays, suggests that these employees engage in supplementary sleep on workdays. Examining the average daily number of sleep periods for workdays and rest days confirmed this hypothesis. A 2 (type of day) × 3 (schedule) ANOVA revealed significant main effects for type of day and schedule, $F(1, 243) = 208.53$, $p < 0.0001$ and $F(2, 253) = 17.41$, $p < 0.0001$, respectively, as well as a significant interaction, $F(2, 243) = 111.96$, $p < 0.0001$. These results indicate that respondents, in general, had more sleep periods on workdays ($\bar{x} = 1.32$) than on rest days ($\bar{x} = 1.10$), and split assignment workers had more sleep periods ($\bar{x} = 1.37$), in general, than either straight through ($\bar{x} = 1.13$) or extra board workers ($\bar{x} = 1.13$).

The sleep results for passenger T&E employees indicate that there is no difference in total daily sleep among the three types of schedules; there are, however, differences among the types of schedules with respect to daily primary sleep and the average number of daily sleep periods. Straight through workers tend to sleep longer on rest days, suggesting that they make up for any sleep deficits that occur during workdays. Split assignment employees have comparable daily sleep on workdays and rest days. Their primary sleep is also less on workdays than rest days; however, they tend to have more sleep periods on workdays than the other two schedule types, suggesting that they offset workday sleep deficits by napping on workdays. Extra board employees tend to have comparable workday and rest day sleep regardless of sleep metric (total daily, primary, or sleep periods). This latter finding is consistent with the T&E employee survey that also examined extra board sleep schedules (Gertler and DiFiore, 2009). The authors speculated that because extra board employees are not able to predict their rest days due to the variability of scheduling, their workday and rest day sleep patterns are indistinguishable.

3.1.6 Combined Work Groups

The previous analyses demonstrate how sleep varies by the type of work schedules that exist in the railroad industry. By combining sleep data across work groups it was possible to examine how sleep varies by comparable types of schedules. Table 13 shows the 12 types of schedules used for the analysis. Daily primary sleep, total daily sleep, and the average number of sleep periods were examined separately with 2 (type of day) x 12 (type of schedule) ANOVAs.

Workday and Rest Day Sleep

As expected from the work group analyses previously described, rest day sleep significantly exceeded workday sleep for both daily primary and total daily sleep for the combined work group data, $F(1, 1546) = 512.52$, $p < 0.0001$ and $F(1, 1535) = 432.31$, $p < 0.0001$. For the combined data, statistical analyses reveal a significant trend of more sleep periods (or naps) on workdays ($\bar{x} = 1.24$) than on rest days ($\bar{x} = 1.12$), $F(1, 1546) = 256.21$, $p < 0.0001$. Overall, these results indicate that workers in this population make up sleep on their rest days and also supplement their sleep with naps on workdays.

Table 13. Schedule Combinations for Combined Sleep Analysis

Schedule	Signalmen	MOW Workers	Dispatcher	Train & Engine Personnel	Passenger T&E
4-day	√	√			
5-day	√	√			
8/6	√	√			
1st Shift			√		
2nd Shift			√		
3rd Shift			√		
Relief			√		
Extra board			√	√	√
Variable start time				√	
Fixed start time				√	
Straight through					√
Split					√

Sleep and Types of Schedules

The analyses demonstrated that the 12 schedules were significantly different from one another for daily primary sleep, $F(11, 1573) = 31.39$, $p < 0.0001$, total daily sleep, $F(11, 1573) = 22.35$, $p < 0.0001$, and the average number of daily sleep periods, $F(11, 1573) = 14.75$, $p < 0.0001$. Figure 13 and Figure 14 show that third shift and relief schedules obtain the least amount of both primary and total daily sleep, whereas split and straight assignment employees obtain the most amount of primary and total daily sleep. Interestingly, employees working third shift, relief, and split assignments report the highest number of daily sleep periods. However, third shift and relief employees do not approach the total amounts of daily sleep that split assignment workers are able to obtain.

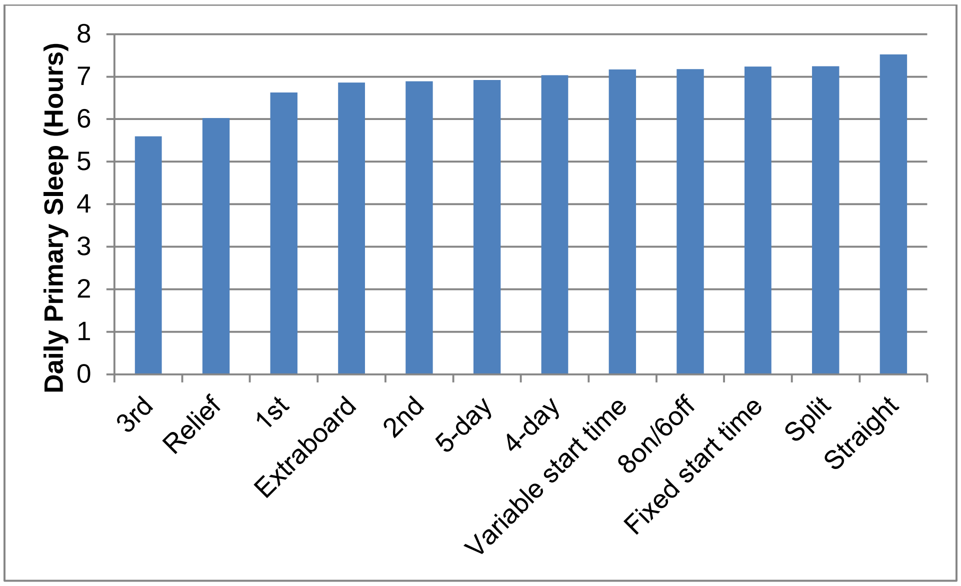


Figure 13. Daily Primary Sleep (Hours) by Type of Schedule

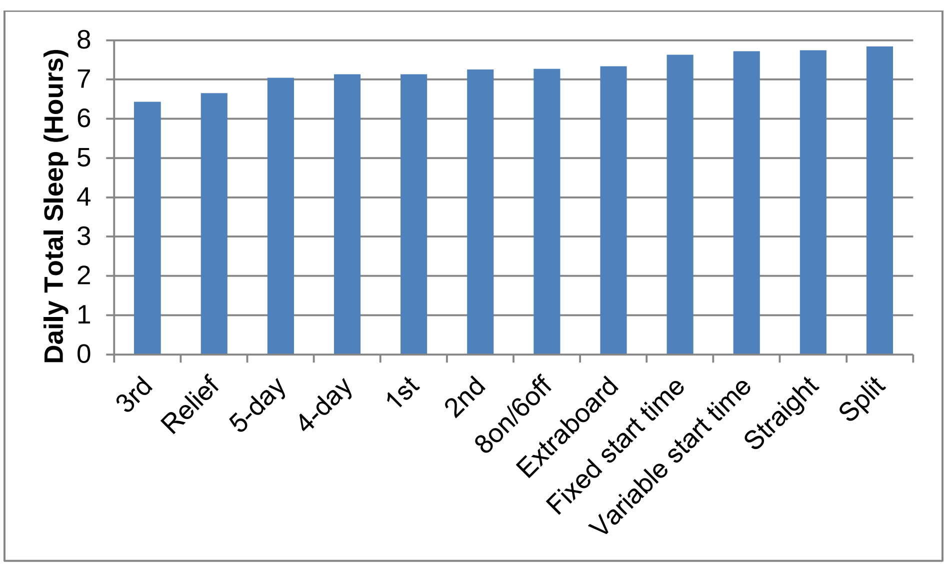


Figure 14. Total Daily Sleep (Hours) by Type of Schedule

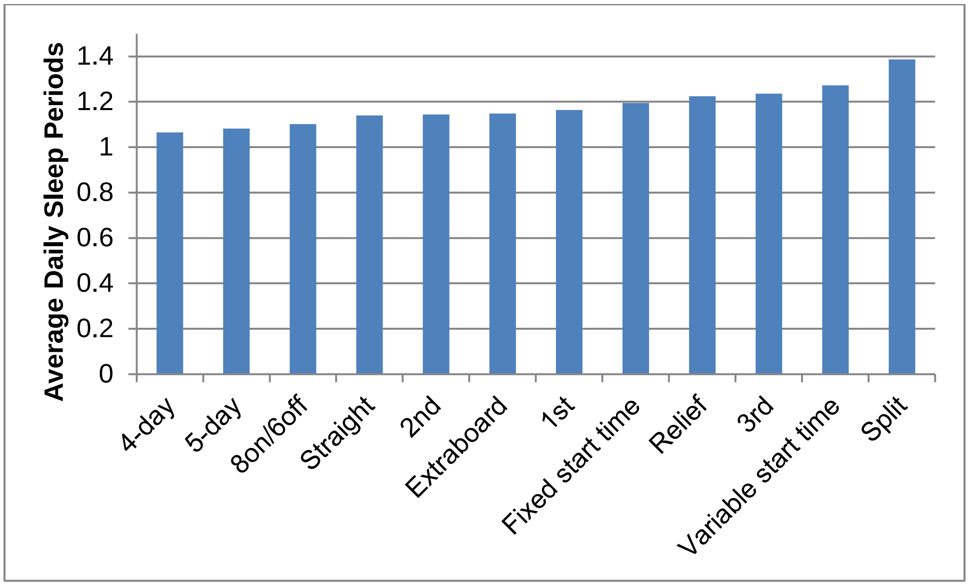


Figure 15. Average Daily Sleep Periods by Type of Schedule

Workday and Rest Day Sleep by Schedule Type

The type of day and schedule interactions for the three metrics of sleep were statistically significant, $F(11, 1546) = 44.83$, $p < 0.0001$ (daily primary sleep), $F(11, 1535) = 53.40$, $p < 0.0001$ (total daily sleep), and $F(11, 1546) = 39.95$, $p < 0.0001$ (average daily sleep periods). The driving factor behind the primary and total sleep interactions is that all but third shift and relief employees exhibited the trend for rest day sleep to exceed workday sleep. With respect to sleep periods, third shift, relief, and split assignment employees to a larger extent than other schedule types had more sleep periods on workdays than on rest days.

Figure 16. Daily Primary Sleep for Work and Rest Days by Schedule

Figure 17. Total Daily Sleep for Work and Rest Days by Schedule

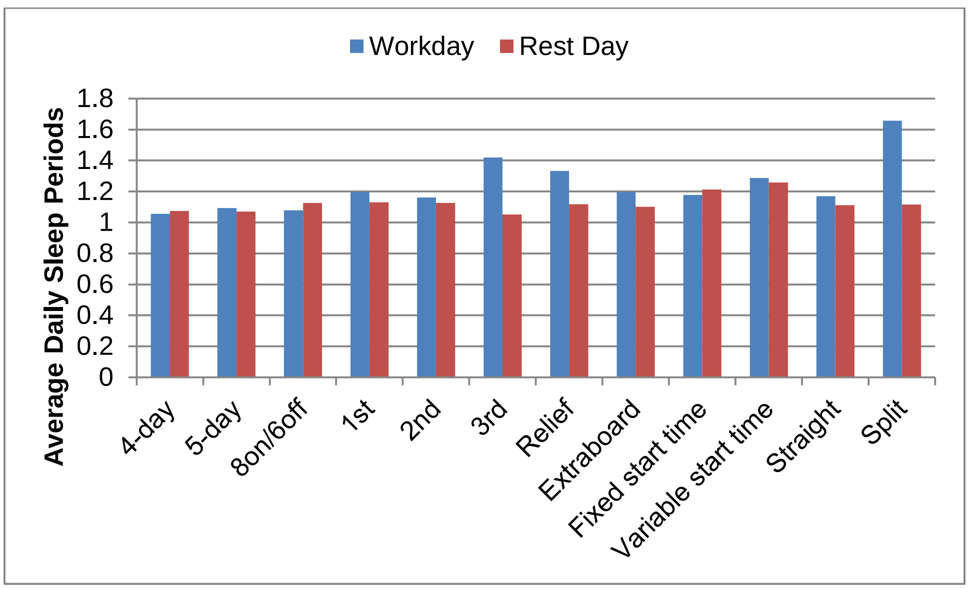


Figure 18. Average Daily Sleep Periods for Work and Rest Days by Schedule

3.2 Comparison with Other Adult Populations

All of the earlier studies compared railroad employee sleep with national data. However, different measures of sleep were used for the different work group comparisons. For example, the comparisons for signalmen and MOW used nighttime (or primary) sleep while the comparisons for the other groups used total daily sleep. To provide a consistent comparison, the following analyses compare total daily sleep for each work group with the results from the National Sleep Foundation's *2008 Sleep in America* poll. The NSF poll reports total sleep time for U.S. working adults on both workdays and non-workdays. The railroad personnel surveys compared only workday sleep with NSF data. The comparisons below include workday as well as rest day sleep.

Statistical analysis comparing the distributions of total daily sleep among the different railroad employee groups and U.S. adults demonstrated that each work group differed significantly from the national data for workday (Table 14) as well as rest day sleep (Table 15).

Table 14. χ^2 (*Df* = 4) Statistics Comparing Railroad Employee Group Total Workday Daily Sleep with 2008 NSF *Sleep In America* Poll of U.S. Adults

Group	Mean Workday Sleep (Hours)	*N*	χ^2	*p*-value
U.S. Adults	6.67	1000	-	-
Signalmen	6.82	388	72.67	$p < 0.0001$
MOW	6.75	252	65.65	$p < 0.0001$
Dispatchers	6.83	443	25.40	$p < 0.0001$
T&E	7.44	250	28.49	$p < 0.0001$
T&E Passenger	7.17	240	12.13	$p < 0.05$

Table 15. χ^2 (*Df* = 4) Statistics Comparing Railroad Employee Group Total Rest Day Daily Sleep with 2008 NSF *Sleep In America* Poll of U.S. Adults

Group	Mean Rest Day Sleep (Hours)	*N*	χ^2	*p*-value
U.S. Adults	7.42	1000	-	-
Signalmen	7.85	379	18.89	$p < 0.0001$
MOW	7.93	242	20.04	$p < 0.0001$
Dispatchers	7.12	425	90.83	$p < 0.0001$
T&E	7.92	246	11.38	$p < 0.05$
T&E Passenger	7.73	235	10.90	$p < 0.05$

Figure 19 shows the comparison between U.S. adults and signalmen for workday sleep. Figure 20 shows the same comparison for rest day sleep. Table 14 and Table 15 show that the mean sleep for both workday and rest day sleep exceed the mean sleep of U.S. adults. The distribution of signalmen workday sleep shows that a larger proportion of signalmen compared with U.S. adults sleep in the 6 h to less than 7 h range. The distribution for rest day sleep, however, shows that rest day sleep shifts to the 7 h to less than 9 h range indicating that these workers make up workday sleep debts on their rest days.

MOW workers and signalmen show a similar distribution for workday sleep: higher in the 6 to less than 7 h range compared with U.S. adults. However, the distribution for rest day sleep shifts to higher amounts of sleep. Table 14 and Table 15 also show that mean sleep for both workday and rest day sleep of MOW employees exceeds the mean sleep for U.S. adults.

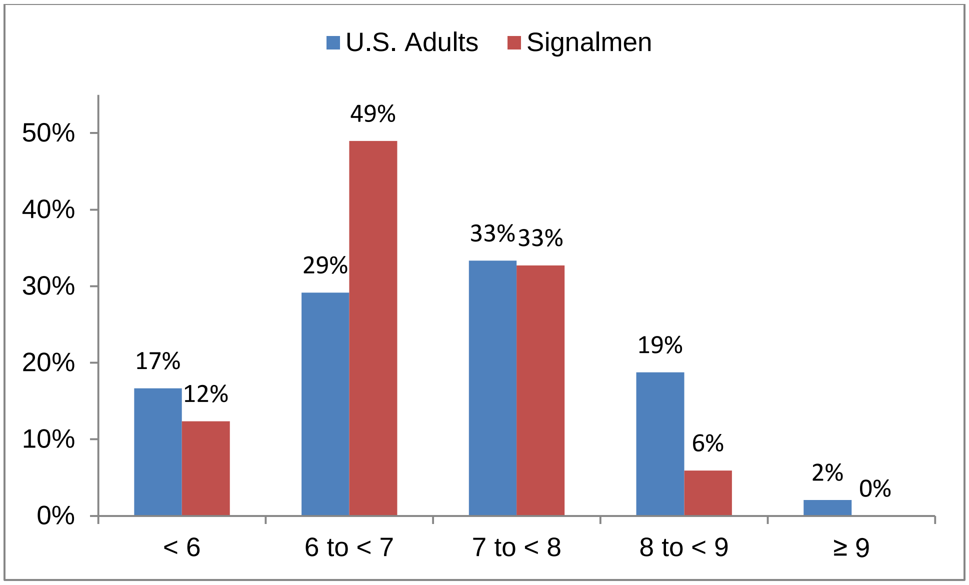


Figure 19. Total Daily Workday Sleep Distributions for Signalmen Compared with U.S. Adults

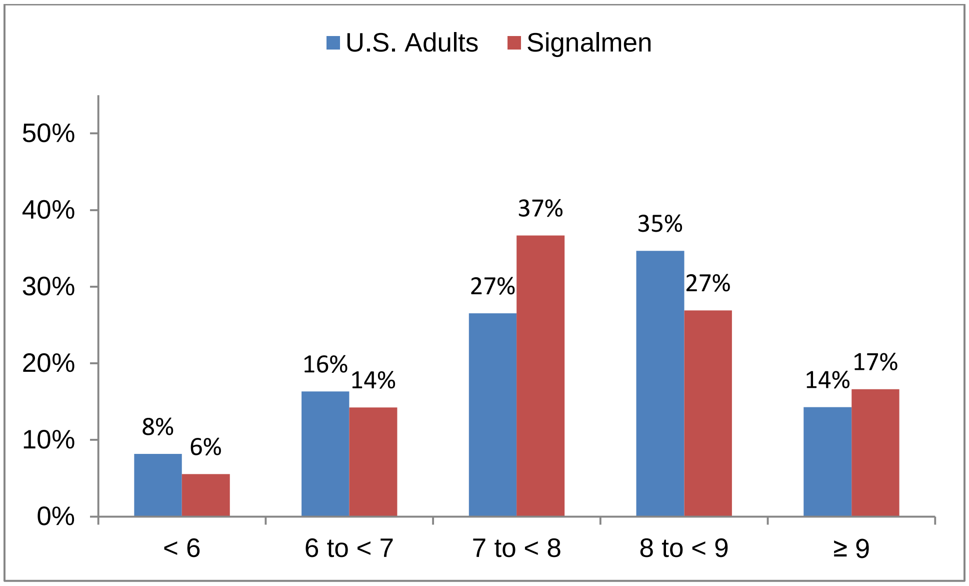


Figure 20. Total Daily Rest Day Sleep Distributions for Signalmen Compared with U.S. Adults

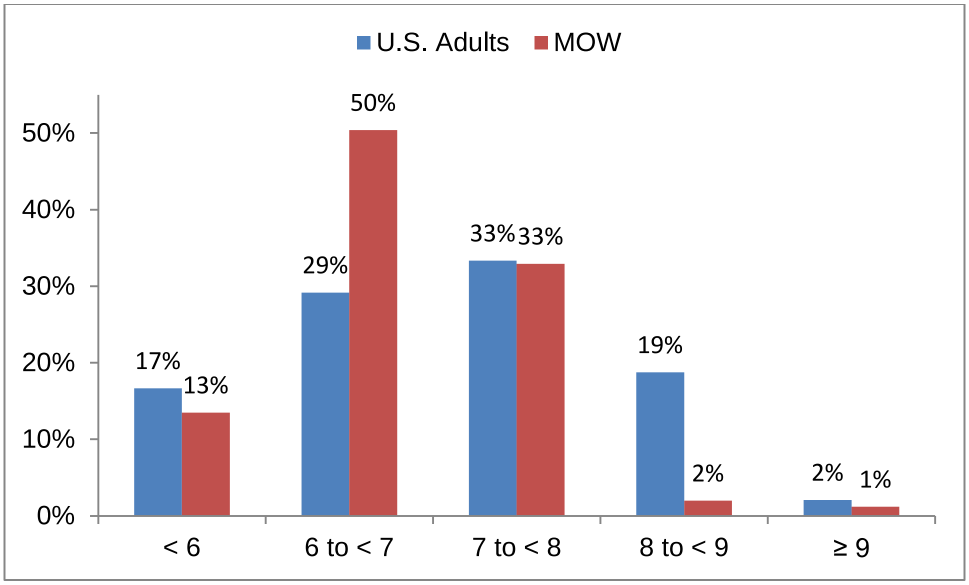


Figure 21. Total Daily Workday Sleep Distributions for MOW Employees Compared with U.S. Adults

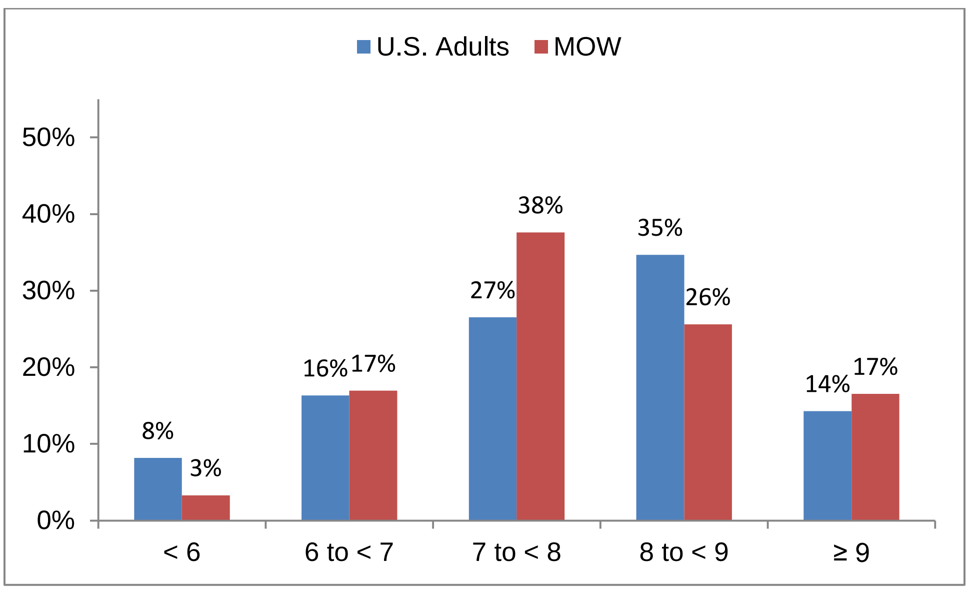


Figure 22. Total Daily Rest Day Sleep Distributions for MOW Employees Compared with U.S. Adults

Dispatchers show a different distribution of sleep compared with U.S. adults (Figure 23 and Figure 24). Dispatchers report more total daily sleep in the less than 6 h range than U.S. adults; this is most apparent on rest days when individuals typically have the opportunity to make up for sleep lost during workdays. U.S. adults show a peak in rest day sleep in the 8 h to less than 9 h category (34 percent), whereas dispatchers most frequently report rest day sleep in the less than 6 h range (21 percent). (Note: There is a higher percentage of dispatchers reporting rest day sleep in the less than 6 h range because several respondents did not have rest days during the 2-week data collection period.)

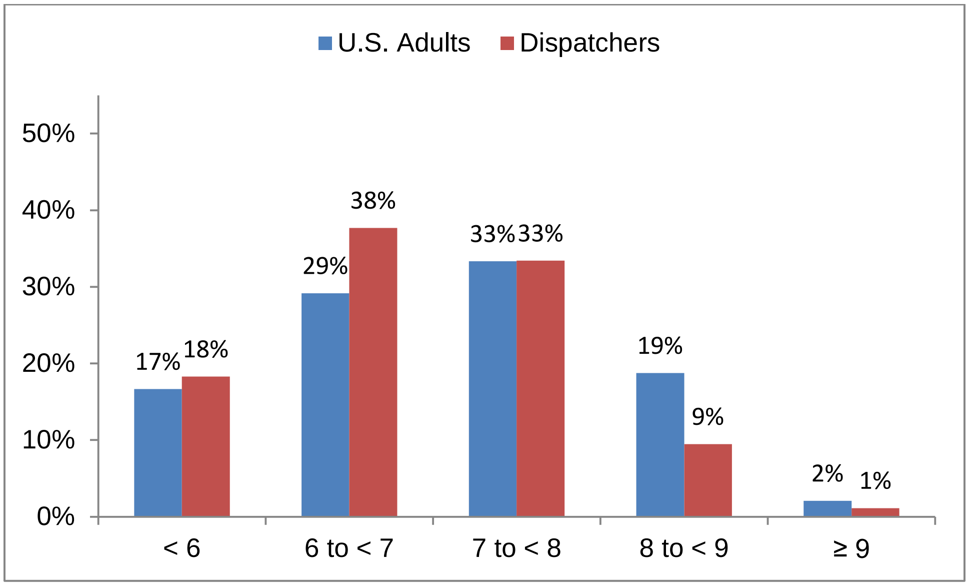


Figure 23. Total Daily Workday Sleep Distributions for Dispatchers Compared with U.S. Adults

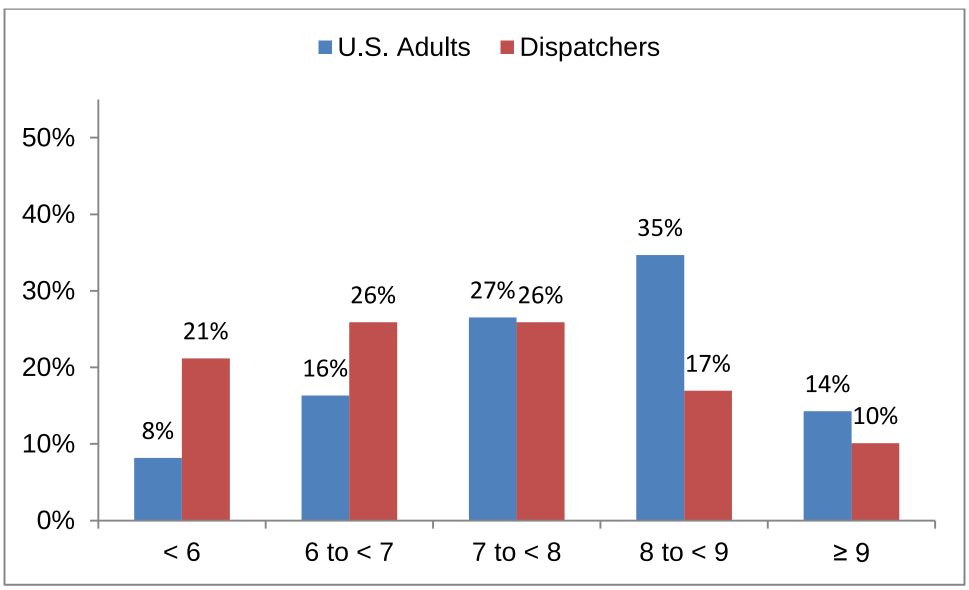


Figure 24. Total Daily Rest Day Sleep Distributions for Dispatchers Compared with U.S. Adults

The survey results from both the T&E survey and the one specifically focused on passenger T&E workers show that, for workday sleep, these employees report less total sleep in the < 6 h range than U.S. adults. Both employee groups show more total sleep in the 7 h to less than 8 h range for workday sleep than U.S. adults. The mean sleep for T&E employees, including passenger workers, exceeds the mean total daily sleep of U.S. adults for both workday and rest day sleep. In addition, the T&E group, passenger employees included, reported more total sleep on both workday and rest days than U.S. adults in the more than 9 h category. Taken together, these results show that T&E employees, including those working in passenger operations, tend to obtain more total daily sleep than typical U.S. working adults.

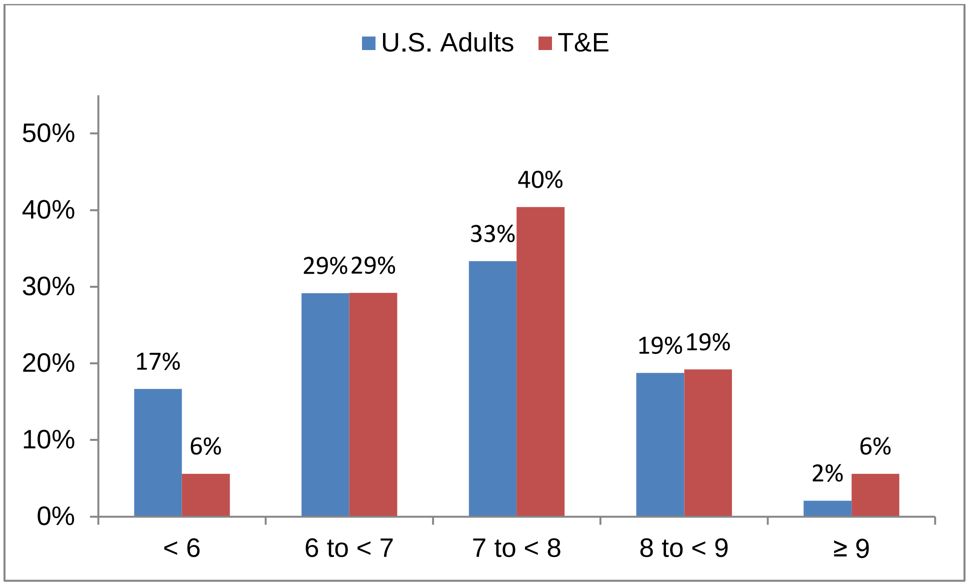


Figure 25. Total Daily Workday Sleep Distributions for T&E Workers Compared with U.S. Adults

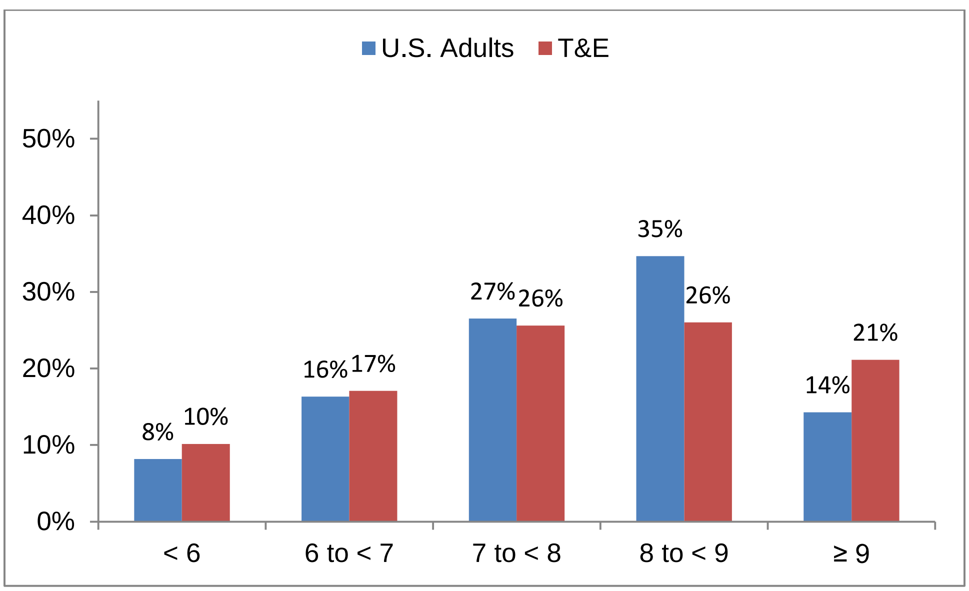


Figure 26. Total Daily Rest Day Sleep Distributions for T&E Workers Compared with U.S. Adults

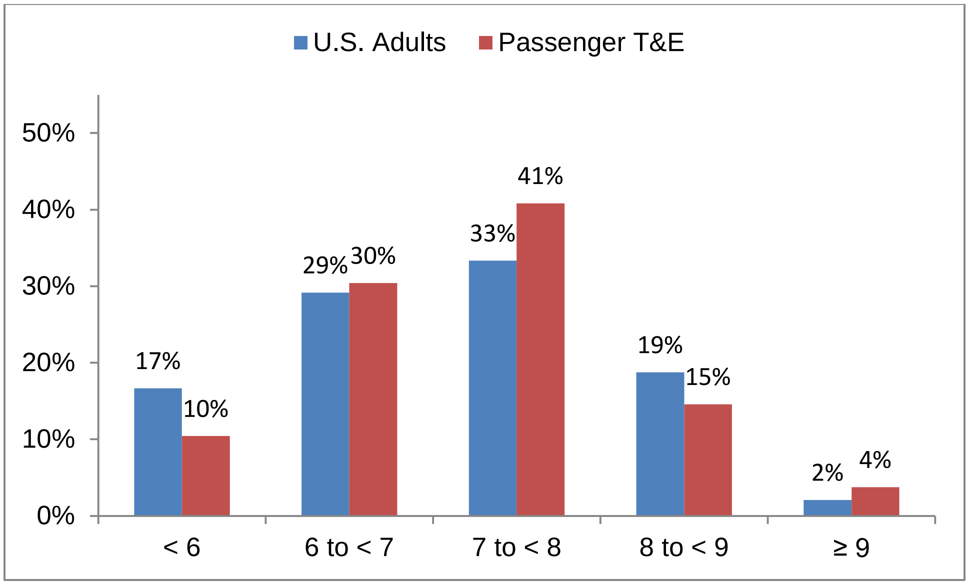


Figure 27. Total Daily Workday Sleep Distributions for Passenger T&E Workers Compared with U.S. Adults

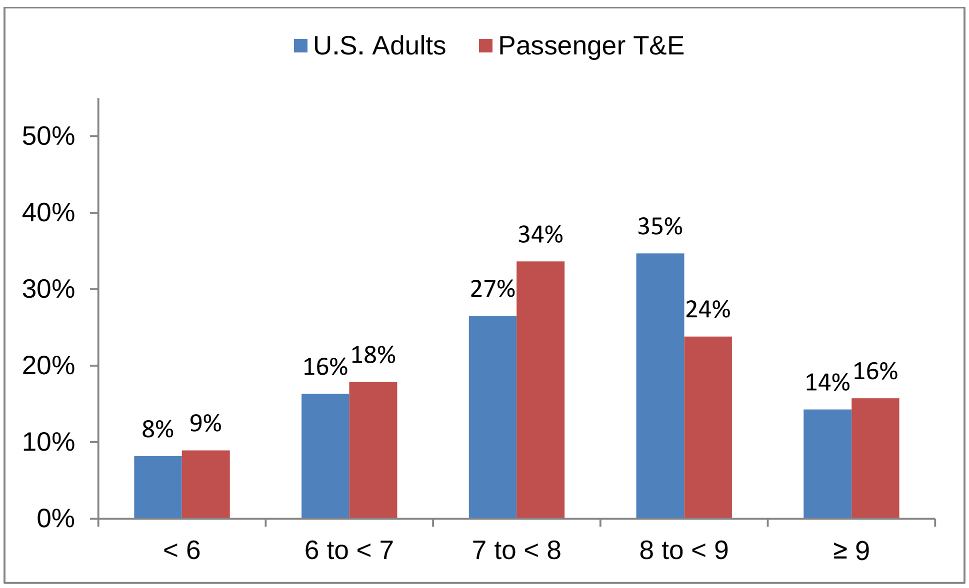


Figure 28. Total Daily Rest Day Sleep Distributions for Passenger T&E Workers Compared with U.S. Adults

3.3 Sleep Quality Ratings

For each survey, respondents were required to record subjective ratings for sleep on both workdays and rest days (or planned days off). Respondents rated their ease of falling asleep, ease of arising, length of sleep, quality of sleep, and alertness upon arising. Respondents rated their sleep using a Likert scale ranging from 1–5, with 1 being the lowest or worst rating, and 5 being the highest or best. The authors refer the reader to the surveys' technical reports for the actual statistical analyses. The descriptions that follow are notable results from those reports.

3.3.1 Job Type and Schedule Effects on Sleep Quality

For signalmen, sleep quality was examined with respect to the type of job performed, construction and non-construction. For virtually every sleep rating, construction signalmen reported better sleep scores than non-construction signalmen. MOW workers' sleep quality was similarly examined by type of job, production and non-production. However, no significant differences regarding sleep quality ratings were evident between the two job types. For dispatchers, there were no significant effects of type of job or shift worked on sleep quality ratings. Variable start time T&E workers consistently rated the quality of their sleep lower than fixed start time workers. These differences were statistically significant for all sleep ratings. For passenger T&E employees, the extra board group had the best sleep ratings. They rated their sleep higher than the straight through group for each quality category; they rated their sleep higher than the split assignment group for "ease of arising," "length of sleep," "quality of sleep," and "alertness upon arising." No significant differences in sleep quality ratings existed between straight through and split assignment groups.

3.3.2 Workday and Rest Day Sleep Quality

The previous section showed that rest day sleep is often longer than workday sleep. Sleep quality is often a function of the length of sleep, and as such, rest day sleep for railroad employees might be expected to be better on rest days than on workdays. However, there were mixed results regarding the statistical significance of sleep quality comparisons between workdays and rest days. Workday and rest day sleep quality was compared for signalmen, MOW employees, and dispatchers. Since the statistical significance of any differences between workday and rest day ratings was marginal, at best, this analysis was not performed for T&E employees.

Regardless of job type, signalmen reported better sleep ratings on rest days than on workdays, and the effect was statistically significant. Like signalmen, MOW workers' sleep quality was examined by type of job, production and non-production. While no significant differences existed between the two groups on either workdays or rest days, both groups rated their sleep quality significantly higher on rest days than on workdays. Dispatchers also gave higher ratings to their rest day sleep as compared with workday sleep; however, these differences were only statistically significant for first shift dispatchers.

3.3.3 Home and Away-From-Home Sleep Quality

For some of the railroad work groups, the job requires the worker to sleep away from home due to the nature of the duties or assignment. Signalmen working construction jobs may work significant distances from their primary residence; as a result, they often sleep away from their home in a hotel or other accommodation closer to the worksite. Data from construction signalmen show that workday sleep ratings were higher at home than away from home; however, only the differences in ratings for ease of falling asleep and quality of sleep were statistically significant.

MOW production crews, as compared with their non-production counterparts, reported spending less than half of their work nights at home, while non-production crews slept at home more than

80 percent of the time. Overall, comparisons of sleep ratings for sleeping at home versus away from home revealed few differences.

For T&E workers, primary sleep periods occurring away from home were significantly shorter than they were at home. Average sleep ratings indicate poorer sleep quality for away sleep compared with home sleep, a statistically significant effect observed for all quality ratings. Compared with fixed start time workers, a larger proportion of primary sleep periods for variable start time workers occur away from home. This may explain why variable start time workers consistently report poorer sleep quality than fixed start time workers.

3.4 Sleep Disorders

The Wisconsin Sleep Cohort Study, a longitudinal study of cardiopulmonary sleep disorders among middle-aged working adults, estimated that 2 percent of women and 4 percent of men have sleep apnea (Young, *et al.*, 1993). (The definition of sleep apnea for this study was an apnea-hypopnea score of 5 or higher and daytime hypersomnolence.) The National Sleep Foundation (NSF) and the National Institutes of Health report the numbers from the Wisconsin study as an estimate of the prevalence of sleep apnea among U.S. adults. Some sleep researchers hypothesize that the prevalence of sleep apnea could in fact be higher, because many individuals remain undiagnosed. According to the Wisconsin study, 9 percent of women and 24 percent of men have undiagnosed sleep-disordered breathing, a condition that in some people results in excessive daytime sleepiness.

All five surveys investigated the incidence of sleep disorders among the different work groups. However, not all of the surveys specifically explored the *type* of diagnosed sleep disorder. The incidence of sleep disorders for the five groups was as follows: 5.7 percent, signalmen; 6.7 percent, MOW; 9.3 percent, dispatchers; 8.4 percent, T&E workers; and 6.6 percent, passenger T&E. Combining these numbers across groups, the industry-wide incidence is 7.4 percent, with 2.4 percent of those diagnosed receiving no treatment for their condition. Untreated sleep disorders present a significant safety risk to railroad operations because of fatigue associated with these types of disorders

Due to the limited number of respondents reporting sleep disorder diagnoses, meaningful comparisons within each work group were not informative. The following analyses combine sleep disorder data across groups to increase the statistical power and relevance of the relationships between various wellness indicators collected from the background surveys and from the sleep quality ratings recorded in the daily logbooks.

3.4.1 Sleep Disorders and Subjective Indices of Well-Being

We chose to examine the effects of sleep disorders and treatment on three background survey questions: perceived health status, perceived age (younger, older, same as chronological age), and general alertness at work. There were no significant differences between treated and untreated respondents for these three questions, χ^2 (3, N = 114) = 0.87, p = 0.83 (perceived health status), χ^2 (2, N = 107) = 4.01, p = 0.13 (perceived age), and χ^2 (3, N = 114) = 3.95, p = 0.27 (general alertness at work). Therefore, these two groups were combined and compared with respondents who reported no sleep disorder diagnosis.

There were no significant differences regarding perceived health between respondents diagnosed with a sleep disorder and those without a sleep disorder diagnosis, χ^2 (3, N = 1584) = 0.87, p =

0.83. However, respondents with sleep disorders were more likely to report feeling older than their chronological age compared with respondents without sleep disorders, χ^2 (3, N = 1521) = 8.71, $p < 0.05$. Approximately half (51.3 percent) of respondents with sleep disorders reported never or only occasionally being alert at work compared with more than a third of respondents without sleep disorders (36.1 percent); this difference was statistically significant, χ^2 (3, N = 1582) = 12.56, $p < 0.01$.

3.4.2 Sleep Disorders and Sleep Quality

We examined the effect of sleep disorder treatment on subjective sleep quality ratings; a Likert scale of 1 to 5 was used, with lower ratings indicating poorer sleep quality for the various questions. There were no significant differences regarding ease of falling asleep between those being treated for sleep disorders and those not being treated, X^2 (4, N = 1552) = 1.63, $p = 0.80$. However, as shown in Table 16, there were significant differences between these two groups for ease of waking, sleep length, sleep quality, and alertness upon waking. The differences were most evident among the lowest sleep quality ratings (1–2). Table 16 shows the relative proportion of responses for the lowest quality ratings from treated and untreated respondents with sleep disorders. Treatment has obvious positive effects on the subjective perception of sleep quality.

Table 16. Significant Sleep Quality Differences between Respondents with Treated and Untreated Sleep Disorders

	Percent of poor sleep quality ratings (1 or 2) for respondents with sleep disorders			
Sleep Quality Rating	**Treated**	**Untreated**	χ^2	***p*-value**
Ease of waking	24.9%	28.9%	11.40	$p < 0.05$
Sleep length	17.7%	28.4%	26.72	$p < 0.001$
Sleep quality	15.5%	24.8%	43.83	$p < 0.001$
Alertness upon waking	15.5%	23.1%	21.23	$p < 0.001$

Having determined that treatment has a positive effect on sleep quality for the respondents with sleep disorders, the next analysis examined whether there were differences between respondents with treated sleep disorders and those without a diagnosed sleep disorder. While there was no difference between these two groups for the subjective rating of sleep length, X^2 (4, N = 21130) = 4.13, $p = 0.39$, there were significant differences for the other sleep quality questions (Table 17). However, there were few meaningful differences in the relative proportion of sleep quality responses rated in the poor range (1–2) (Table 17), with the exception of ease of waking. These results demonstrate that treating sleep disorders has a positive effect resulting in nearly indistinguishable sleep quality ratings between those with treated sleep disorders and those without sleep disorders. Sleep disorder education efforts in the workplace could be one mitigation effort for this risk.

Table 17. Significant Sleep Quality Differences between Respondents with Treated Sleep Disorders and without Sleep Disorders

	Percent of poor sleep quality ratings (1 or 2) for respondents with sleep disorders			
Sleep Quality Rating	**Treated Sleep Disorder**	**No Sleep Disorder**	χ^2	***p*-value**
Falling asleep	11.5%	11.0%	26.66	$p < 0.001$
Ease of waking	24.9%	21.4%	12.06	$p < 0.05$
Sleep quality	15.5%	14.9%	10.46	$p < 0.05$
Alertness upon waking	15.5%	15.3%	9.61	$p < 0.05$

3.5 Fatigue Education

The background survey for both T&E studies asked about participants' exposure to educational materials or training on fatigue, sleep hygiene, napping, and sleep disorders. (This question was not part of the earlier surveys.) Three quarters of the T&E group reported having some type of fatigue education, but a quarter reported that they never had this type of training. More than half of the passenger T&E group reported having no fatigue education. A brochure was the most common type of fatigue training for the passenger group; for the larger T&E group the most common type of training was both a brochure and a videotape.

3.6 Alertness

For each survey, respondents provided an assessment of their alertness by recording subjective ratings of their alertness upon waking and at three other times during the day. They rated their alertness using a Likert scale ranging from 1 to 5 with 1 indicating "very sleepy" and 5, "very alert." In addition, they answered a question on the background survey that asked about their overall alertness while at work. The prior technical reports contain details of the statistical analysis of the data from each survey. This section provides highlights of the results from these earlier reports. The only new analysis undertaken with these data was an analysis to examine the relationship between consecutive days with work starts and start of work alertness. No relationship was found.

3.6.1 Workday Ratings

Alertness ratings from all groups showed that alertness peaked upon arrival at work and declined throughout the day. The one exception was the split shift passenger T&E group. Their alertness increased at the end of the second half of their workday, but this increase was not statistically significant. For signalmen, the construction group had higher alertness ratings throughout the day. For MOW, there was no difference between production and non-production workers. Third shift dispatchers showed the greatest decline in alertness from start to end of their shift. Since they work at night, this was not an unexpected finding.

The analysis of T&E data compared ratings of alertness at the start and end of work. Variable start time workers rated their level of alertness significantly lower than fixed start time workers. Differences in alertness ratings also existed based on the length of the work period, especially for work periods of 9 h or more. For the passenger T&E group significant differences existed between ratings for the start and end of work, as well as among the three schedule types.

3.6.2 Overall Alertness

Analysis of the background survey question regarding overall alertness at work found significant differences by schedule group for the dispatchers and the T&E group overall. Responses for the two groups of signalmen and the two groups of MOW workers did not show a significant difference in their overall alertness assessments. The same was true for the three groups of passenger T&E workers. Since this question did not prove particularly useful in identifying differences, perhaps future surveys should use only the logbook ratings to evaluate alertness.

3.7 Summary

As expected, sleep patterns in the five groups reflected work schedule characteristics. Analysis of sleep patterns considered both primary and total daily sleep. Across the groups, rest day sleep significantly surpasses workday sleep for both primary and total daily sleep. There are 12 distinctive types of work schedules among the groups, and these schedules are significantly different with regard to primary sleep, total sleep, and number of daily sleep periods. Third shift and relief schedules get the least amount of primary and total daily sleep, while split and straight assignment employees get the most. Employees working third shift, relief, and split assignments have the highest number of daily sleep periods. Although analyses of individual work groups confirmed many expectations based on work schedules, they also revealed many unexpected differences among work schedules. For instance, T&E workers working jobs with a fixed starting time were more likely to make up sleep on rest days than those working jobs with a variable starting time. This may be due to the schedule inconsistency of variable start workers. Both unexpected calls to duty and start time variability may prevent this group from dedicating specific time periods to long, uninterrupted sleep; consequently, they are unable to distinguish between work and rest days for the purpose of planning sleep.

Statistical analysis comparing total daily sleep among the different railroad employee groups and U.S. working adults for both workdays and rest days found each work group differed significantly from national data, but the pattern of differences varied by group. The mean workday sleep for all groups exceeded that of U.S. adults on workdays, but the railroad workers had a greater proportion of sleep under 7 h. In contrast, on rest days, all but dispatchers had a mean daily sleep that exceeded that of U.S. adults, and the railroad groups had a higher proportion of sleep times over 7 h compared with U.S. adults. Overall, railroad workers as a group make up more sleep on rest days than U.S. working adults.

Railroad workers in all groups reported sleep disorders that exceed U.S. norms for working adults. Of these, all but 2.4 percent were receiving treatment. Comparison of the reported sleep quality for those undergoing treatment with those not doing so indicated that the treated group was less likely to report poor sleep quality.

4. Fatigue Exposure

As noted in Section 1, early mathematical models of sleep regulation were two-process models. They modeled the homeostatic drive for sleep and the circadian rhythm of sleep and alertness. However, in an operational setting, knowing the relative alertness or sleepiness (fatigue) of a person does not provide sufficient information about the consequences of that level of fatigue on operational performance. In the 1980s, the Department of Defense (DOD) recognized the need to link fatigue and performance because military personnel are often required to perform complex tasks during sustained and continuous military operations[7] (Hursh, *et al*, 2004a). Sleep deprivation is the immediate consequence of such operations, and DOD determined to model cognitive performance as a function of circadian rhythms and sleep deprivation. The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) biomathematical model was developed as a result of these DOD efforts. Subsequently, in 2001, FRA contracted with the developers of SAFTE to adapt the model for use in a railroad environment. FRA required that the model demonstrate a relationship between operational performance and accidents. This was termed "model validation" and was intended to demonstrate that the model, which was based on numerous laboratory tests, had "real world" validity. During that same time period, FRA also supported efforts by an Australian university to promote the use of its fatigue model (see Roach, Fletcher, and Dawson, 2004). FRA's intention was that the Fatigue Audit Interdyne™ (FAID) model would offer the railroad industry—an industry known to insist on multiple vendors for products and services—an alternative to the SAFTE model.

Biomathematical models of performance and fatigue are now used to predict a railroad worker's level of fatigue and resulting performance degradation based on work schedules. A new regulation concerning hours of service of railroad employees providing commuter and intercity rail passenger transportation (49 C.F.R. § 228) requires the use of a validated and calibrated fatigue model to analyze work schedules under circumstances specified in the regulation. FRA has approved two models for use by railroads in meeting the requirements of 49 C.F.R. § 228: Fatigue Avoidance Scheduling Tool™ (FAST) which is based on SAFTE, and FAID. The following section discusses the AutoSleep component of FAST and also presents analyses of work schedules and sleep using the FAST tool to determine the fatigue exposure of the five work groups.

4.1 Fatigue Modeling

The SAFTE model (Figure 29) is incorporated in FAST, a software tool for analyzing work schedules (Hursh, Balkin, Miller, and Eddy, 2004b). The model contains the two processes that are basic to all fatigue models: a sleep reservoir and a circadian oscillator. The sleep reservoir represents sleep-dependent homeostatic processes that control cognitive performance. The reservoir is depleted during wakefulness and replenished during sleep. The rate of replenishment depends on sleep intensity and quality. Sleep intensity is determined by circadian processes and the level of the reservoir or sleep debt. Cognitive performance, or effectiveness, is modulated by TOD and sleep debt. The FAST effectiveness score is a measure of cognitive performance based

[7] Sustained and continuous military operations require wakefulness for extended periods of time, sometimes days, at all times of day.

on reaction speed on a psychomotor vigilance test. Effectiveness is the inverse of fatigue and ranges from 0 (the most fatigued) to 100 (the least fatigued).

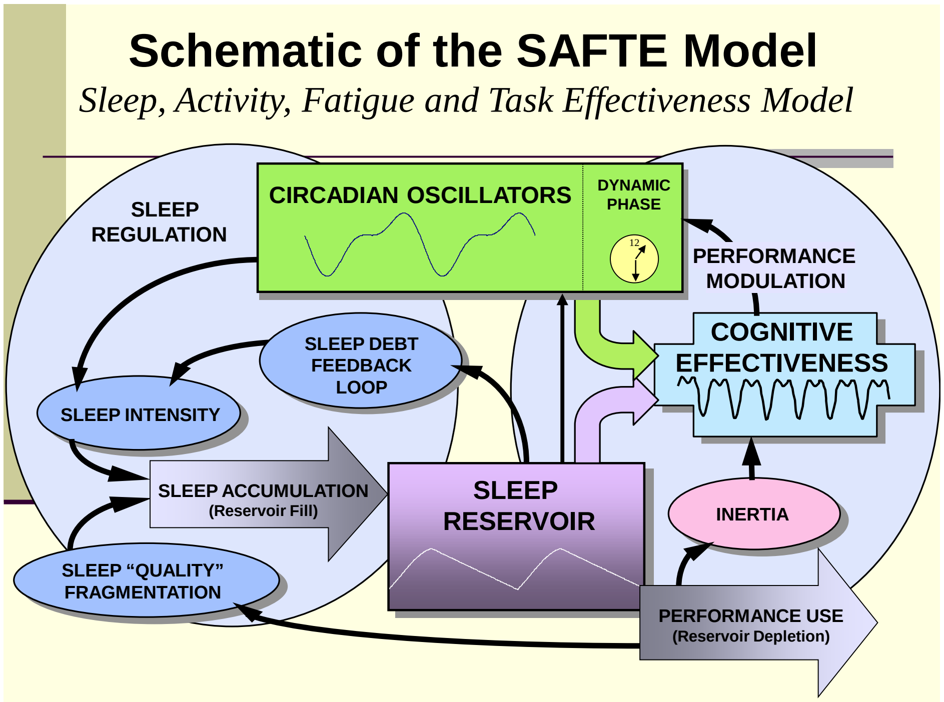


Figure 29. Schematic of SAFTE Model

As noted above, SAFTE and FAST were developed from laboratory studies of sleep deprivation and restoration. FRA deemed it critical to establish that the model is valid in the railroad environment. To do this, 30-day work histories were obtained for 400 human factor caused and 1,000 nonhuman factor caused railroad accidents (for full details see Hursh *et al.*, 2006, 2008). The work histories were analyzed by FAST to determine the effectiveness or fatigue level of employees at the time of the accidents. It was hypothesized that human factors accidents would be more likely to occur at increased fatigue levels (decreased effectiveness), and that nonhuman factors accidents would have no relationship to effectiveness. Hursh *et al.* found a statistically reliable relationship between decreases in effectiveness and human factors accident risk, but no reliable relationship between effectiveness and nonhuman factor accidents. This finding demonstrated the validity of FAST in a railroad operational environment. Table 18 shows the cumulative human factors accident risk as a function of effectiveness. Table 18 also shows the percent of work time at various effectiveness levels. While all the criterion effectiveness scores were statistically different from chance (risk = 1.0), it was only at effectiveness scores ≤ 70 that effectiveness was also statistically different from nonhuman factors accident risk (1.06). This is the basis for the fatigue threshold established under 49 C.F.R. § 228: a work schedule that has 20 percent or more work time at or below an effectiveness score of 70 is considered to have an excessive risk of fatigue.

Table 18. Human Factors Accident Cumulative Risk at Various Criterion Levels of Effectiveness (after Hursh *et al.*, 2006, 2008)

Criterion Effectiveness[#] Score	*Human Factors Accident Risk (%)*	*Percent of Work Time*	*Human Factors Cases Number (Percent)[+]*
> 90	**- 16 ***	42	259 (35%)
≤ 90	**+ 11 ***	58	472 (65%)
≤ 80	**+ 14 ***	35	289 (40%)
≤ 70	**+ 21 *†**	19	166 (23%)
≤ 60	**+ 39 *†**	7	71 (10%)
≤ 50	**+ 65 *†**	2.7	33 (4.5%)

* Significantly different from chance ($p < 0.05$)

† Significantly different from nonhuman factors accident risk ($p < 0.05$)

[#] Effectiveness at accident time based on 30-day work histories processed using the SAFTE biomathematical fatigue model

[+] Human factors cases (two crewmembers per accident) in 2.5 years, excluding accidents involving consistent night workers. The percentages above and below 90 sum to 100 percent. The percentages below 90 are cumulative and do not sum to 100 percent.

To provide a better understanding of what it means to have a particular effectiveness score, Table 19 and Table 20 relate effectiveness to other measures such as the likelihood of a lapse,[8] sleep history, and blood alcohol concentration (BAC). The effectiveness scores in Table 19 are based on a person who has 8 h of sleep, wakes at 7 a.m., and remains awake for the amount of time indicated. An effectiveness score of 70 is the equivalent of being awake for 21 h, or having a BAC of 0.08, and lapses are five times more likely than for a well-rested person.

Table 20 assumes that a person wakes at 7 a.m. after obtaining the amount of sleep in the first column, or losing the amount of sleep in the second column. At 4 p.m. performance is almost optimal. At 4 a.m. performance reflects the combined effects of prior sleep, TOD, and 21 h of wakefulness.

[8] A lapse is an excessively long reaction time caused by a microsleep or loss of alertness.

Table 19. Relationship Among Various Effectiveness Scores and Other Meaningful Metrics: Likelihood of a Lapse, Continuous Hours Awake, and BAC (after Hursh *et al.*, 2006, 2008)

Effectiveness Score	Lapse Likelihood	Hours Awake (Hr:Min)	BAC Equivalent
98	0.2	14:00	
94	1.0	15:10	
90	1.5	16:00	
80	3	18:00	
77	**4**	**18:30**	**0.05**
70	**5**	**21:00**	**0.08**
69	5.4	22:00	
60	8	40:50	
50	12	42:30	
40	18	64:00	

Table 20. Effects of Various Daily Sleep Patterns on Effectiveness Estimates at 1600 h and 0400 h. Three Schedules: 1, 2, 7 Days at the Specified Sleep Level (after Hursh *et al.*, 2006, 2008)

Prior Daily Sleep (H)	Prior Daily Sleep Loss (H)	Effectiveness Score After:					
		One Day		Two Days		Seven Days	
		1600 h	0400 h	1600 h	0400 h	1600 h	0400 h
8	0	97	70	97	70	97	70
7	1	96	69	95	68	93	67
6	2	94	68	92	66	88	63
5	3	92	65	89	62	82	57
4	4	90	63	84	58	72	48
3	5	87	59	78	51	57	34
2	6	83	55	70	42	*	*
1	7	78	49	58	30	*	*
0	8	73	43	46	15	*	*
* No data available for these conditions							

It is useful at this point to establish a nomenclature for describing the fatigue level associated with effectiveness scores. A nomenclature, unlike numerical scores, allows easier discussion of research results, without loss of information. Table 21 shows fatigue categories as a function of FAST effectiveness score. There are three important categories in this scheme.

Table 21. Fatigue Levels and Corresponding FAST Effectiveness Scores

	Severely Fatigued	Extremely Fatigued	Very Fatigued	Moderately Fatigued	Fatigued	Not Fatigued
Cumulative	≤50	≤60	≤70	≤80	≤90	>90
Interval	≤50	51 - 60	61 - 70	71 - 80	81 - 90	>90

Effectiveness scores > 90 indicate a lack of fatigue, scores ≤ 90 indicate some fatigue, and scores ≤ 70 indicate a very fatigued state and correspond with the fatigue threshold. The fatigue exposure in a work schedule may be simply characterized by reference to these three categories or completely described by using all categories. Work schedules will typically have a proportion of work time in all categories. When plotted as a cumulative distribution function[9] (CDF), FAST effectiveness score CDFs often resemble a power function distribution[10] (see Evans, Hastings, and Peacock, 2000) for a description of power function distributions). Figure 30 provides examples of truncated CDFs. Through a convention of probability theory, CDFs like these can provide estimates of the probabilities of fatigue or effectiveness associated with the work schedule from which they were generated (see Hays, 1963, p. 58). Hence, summary statistics, such as the mean and variance, provide descriptive information about the fatigue status of the population under consideration.

The FAST model provides a means to assess the risk of fatigue in work schedules and to plan schedules that reduce fatigue. The model considers the TOD when work occurs and opportunities for sleep based on that work schedule. It can be used with work schedules alone or with both work schedules and sleep data. If only work schedule data are available, the AutoSleep component of the model predicts when the typical individual working the schedule will sleep. Since the survey data, as described below in subsection 4.2, included both work and sleep periods, use of AutoSleep was not necessary.

4.2 Fatigue Exposure at Work

As noted above, FAST effectiveness is based on reaction speed on the psychomotor vigilance test. FAST computes effectiveness as the percentage of the performance of the average well-rested daytime worker for each half hour of the work period. Of particular concern is time spent at or below 70 percent effectiveness. This effectiveness level corresponds to a reaction time that is 1.4 times that of a well-rested person, cognitive throughput that is 81 percent of a well-rested individual’s, and five times the likelihood of a lapse in attention relative to a well-rested person. Estimating the distributions of work time by effectiveness level for different groups of employees offers a means to determine where fatigue exposure exists and where fatigue risk management resources would be most effective.

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[9] A cumulative distribution function maps the range of the x variable onto the probability domain (0,1). In this case, the cumulative proportion of work time is a function of effectiveness. Cumulative distribution functions always have a domain from 0 to 1. The analysis in this report truncates the domain at ≤ 90 and plots the proportion > 90 separately to clearly indicate the “not fatigued” category. The proportion ≤ 90, when added to > 90, sums to 1.

[10] Power functions are linear in log-log coordinates. There is no theoretical basis for effectiveness CDFs to be of this form, so there is no further analysis of this form.

The work and sleep data from each of the five sets of survey data were analyzed separately with FAST. Figure 30 shows the cumulative proportion of work time as a function of effectiveness (fatigue exposure) for accidents (Hursh *et al*, 2006, 2008), signalmen (Gertler and Viale, 2006a), MOW workers (Gertler and Viale, 2006b), dispatchers (Gertler and Viale, 2007), T&E crews (Gertler and DiFiore, 2009), and passenger T&E crews (Gertler and DiFiore, 2011). The fatigue exposure of accidents at the fatigue threshold (≤ 70) and ≤ 90) is well above that for any of the work groups. Conversely, the proportion of work time not fatigued (> 90) is the lowest for accidents. Figure 31 demonstrates this more clearly because it shows only the data for ≤ 70, ≤ 90, and > 90. Figure 32 shows the mean FAST scores for the five work groups and accidents. Accidents have the lowest mean effectiveness (highest mean fatigue), followed by T&E, dispatchers, MOW, signalmen, and passenger T&E. Clearly, high exposure to fatigue is a characteristic of human factor accidents. T&E crews and dispatchers are also highly exposed to fatigue. The best way to characterize fatigue exposure is an unresolved question.

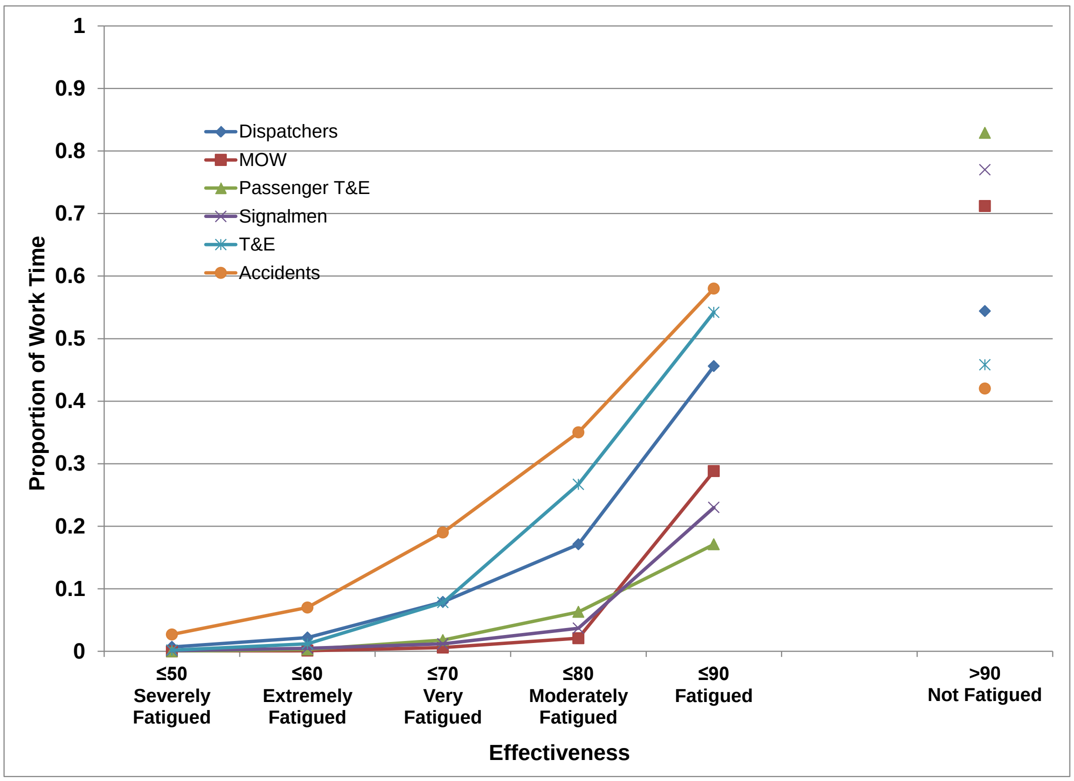

Figure 30. Fatigue Exposure by Work Group and T&E Workers Involved in Accidents

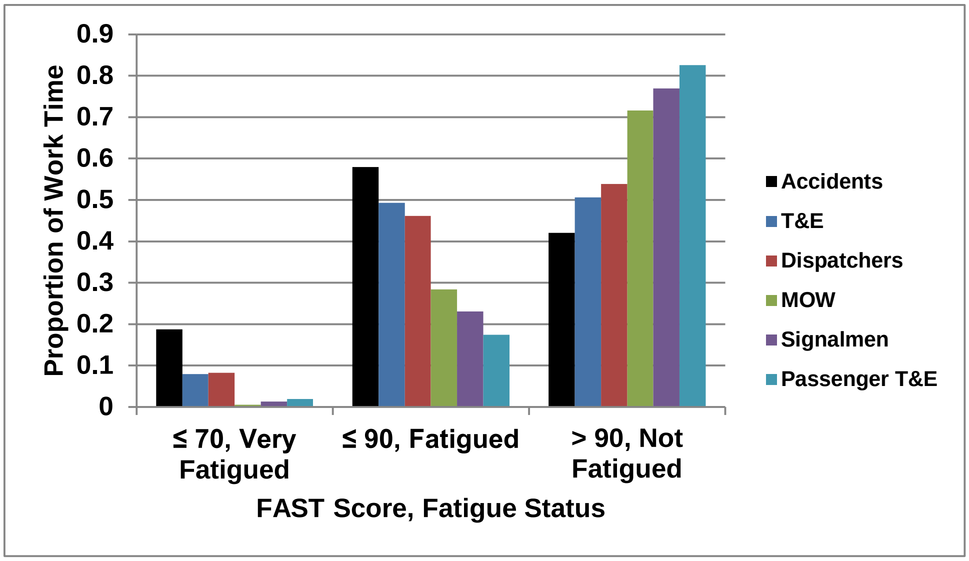

Figure 31. Fatigue Exposure by Work Group and for Accidents

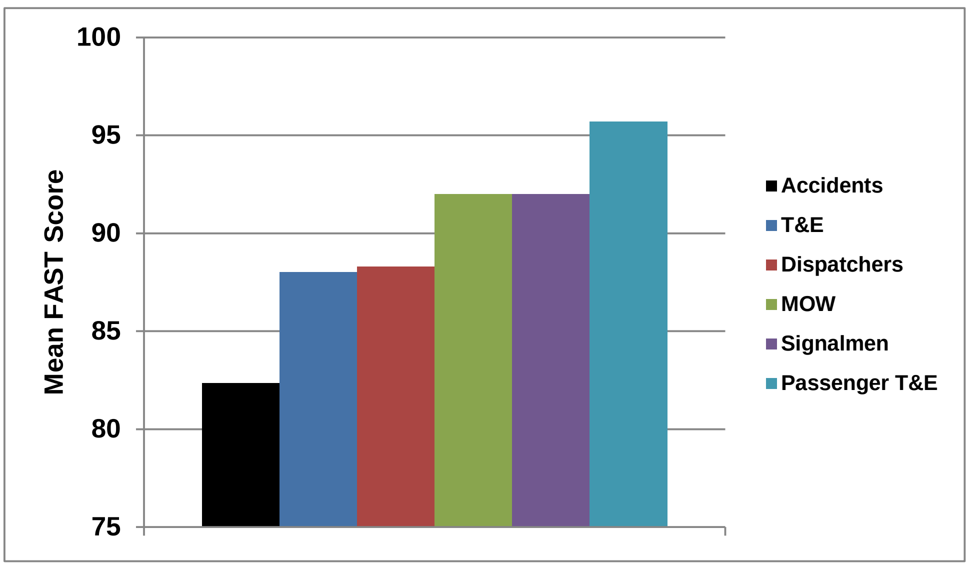

Figure 32. Mean FAST Scores (Fatigue Exposure) for Work Groups and Accidents

Table 22 presents a detailed summary of the FAST effectiveness analysis for each of the five employee groups. Three effectiveness categories are presented: at or below the critical level of 70, at or below 90, and over 90, which corresponds to no fatigue. The third shift dispatchers, who commonly start work between 10 p.m. and midnight and work more than 4 hours after midnight, have the most exposure to severe fatigue: ≤ 70, 31.5 percent. Many other railroad jobs are basically day jobs, so their exposure to severe fatigue is considerably lower. Most T&E crews have an irregular schedule and their fatigue exposure is slightly less than 8 percent of working hours. In contrast, T&E passenger jobs working split assignments and second shift dispatcher jobs have very little fatigue exposure and nearly all of their work time is at the "not fatigued" level. Second shift jobs do not require the employee to wake up early, so this group tends to get adequate rest. While split assignment jobs may require an early start and less nighttime sleep, the analysis of the sleep data for this group indicated that they frequently sleep during the interim release period between the two daily work periods (see Gertler and DiFiore, 2011).

Table 22. FAST Effectiveness Results by Group and Work Schedule

Group	**Work Schedule**	**Mean FAST Score**	**≤70 Very Fatigued**	**≤90 Fatigued**	**>90 Not Fatigued**
Signalmen	4 on	92.4	0.7%	21.1%	78.9%
	5 on	92.0	1.4%	22.8%	77.2%
	8 on/6 off	90.3	1.5%	30.7%	69.3%
	Mean (SD)	92.0 (8.3)	1.2%	23.0%	77.0%
MOW	4 on	91.6	0.3%	31.4%	68.6%
	5 on	92.2	0.7%	27.8%	72.2%
	8 on/6 off	91.8	0%	25.5%	74.5%
	Mean (SD)	92.0 (4.3)	0.6%	28.8%	71.2%
Dispatchers	1st shift	90.3	0.3%	44.5%	55.5%
	2nd shift	94.9	0.4%	13.0%	87.0%
	3rd shift	76.6	31.5%	82.9%	17.1%
	Relief	86.9	8.6%	53.8%	46.2%
	Extra board	88.3	7.4%	49.6%	50.4%
	Mean (SD)	88.3 (9.3)	7.9%	45.6%	54.4%
T&E	Fixed start	89.4	7.7%	37.7%	62.3%
	Variable start	87.3	7.8%	54.2%	45.8%
	Mean (SD)	88.0 (8.9)	7.8%	54.2%	45.8%
T&E passenger	Straight through	95.2	2.5%	19.6%	80.4%
	Split	97.3	0%	7.9%	92.1%
	Extra board	96.1	1.0%	15.2%	84.8%
	Mean (SD)	95.7 (6.1)	1.8%	17.1%	82.9%
Grand Mean (SD)		91.6 (8.4)	3.9%	32.0%	68%
T&E Accidents		82.3(15.4)	18.8%	58.0%	42.0%

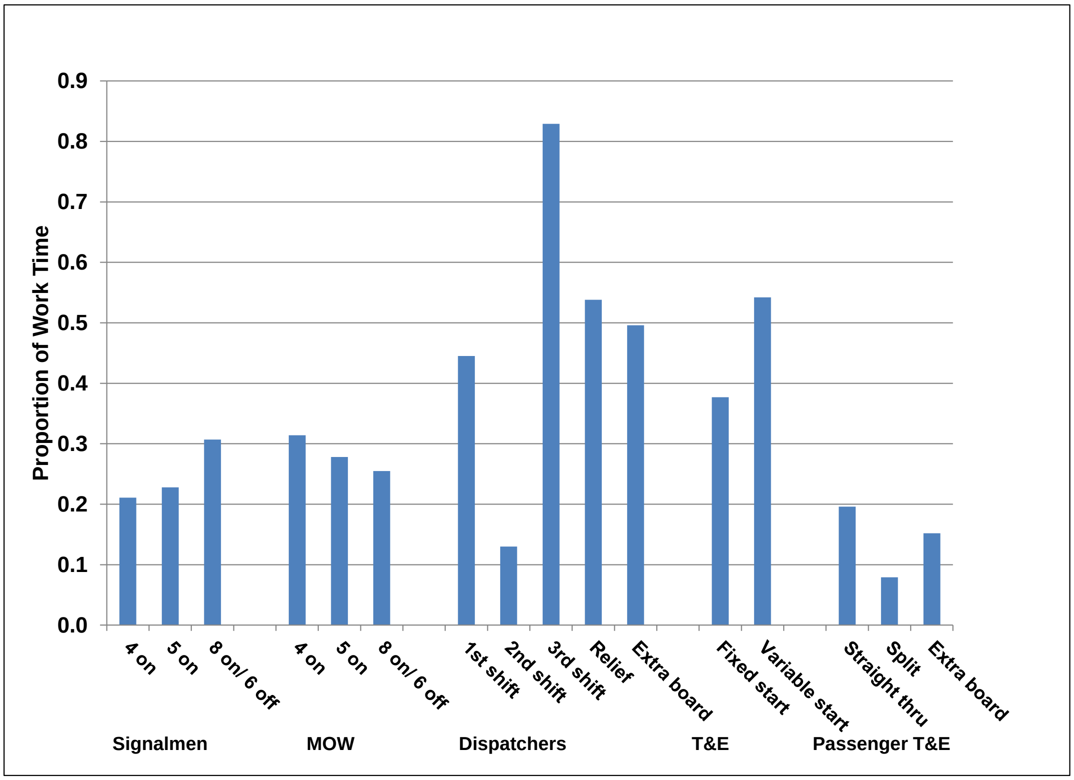

Figure 33. Percent Fatigued (≤90 Effectiveness) by Group and Work Schedule

The data for the fatigued groups (≤ 90) are plotted in Figure 33. The groups with the highest proportion of fatigued work time are dispatchers (with the exception of second shift) and T&E. Third shift dispatchers have the highest proportion of fatigued work time followed by variable start T&E, relief dispatchers, and extra board dispatchers. All of these jobs involve night work and/or circadian disruption.

Examining the number of work hours of fatigue exposure is one means of assessing relative fatigue risk across employee groups. The Surface Transportation Board provides service hours by employee group. Using these data, it is possible to estimate the annual work hours of exposure to fatigue (see Table 23). Although the proportion of T&E labor-hours at risk of fatigue is relatively low, because this group accounts for about 40 percent of railroad industry labor-hours, the total number of T&E labor-hours at low effectiveness is nearly 10 million annually.

Table 23. Fatigue Exposure by Labor-Hours and Employee Group

Group	% at ≤70 Effectiveness	2010 Class I Railroad Labor-Hours (K)[11]	Labor-Hours at Risk (K)
MOW & Signalmen	1.1%	75,994	963
T&E	7.6%	127,649	9,701
3rd Shift Dispatchers	31.5%	2,796	881

4.3 Validation of AutoSleep

A key element of SAFTE-FAST is the AutoSleep module which predicts when the individual working the schedule may sleep. AutoSleep was developed using data from an FRA-sponsored study which in 1992 collected data from 204 railroad engineers (Pollard, 1996). Subsequently, FRA sponsored the series of diary studies described in this report. The data from these studies were compared with AutoSleep predictions from FAST (Federal Railroad Administration, 2011). Table 24 presents the results of this analysis.

Table 24. Accuracy of AutoSleep Predictions

Group	Mean Agreement	Error (AutoSleep Estimate – Logbook Data)
Signalmen	92%	-24 min
MOW	92%	-21 min
1st and 2nd Shift Dispatchers	90%	-3 min
T&E (except regular night workers)	88%	-10.8 min
3rd Shift Dispatchers	79%	+18.8 min
Night T&E	82%	-40.2 min

As Table 24 indicates, the AutoSleep predictions were most accurate for the signalmen and MOW workers. Both are primarily daytime jobs. The first and second shift dispatchers work daytime hours but many first shift dispatchers must get up early for an early morning shift start. The third shift dispatcher and T&E people who had at least 50 percent of their work starts between 10 p.m. and 4 a.m. were analyzed with different AutoSleep parameters to reflect their different sleep patterns on workdays. The predictions for these two groups were not as accurate as those for the other groups; AutoSleep under-predicted daily sleep for night T&E by 40 min.

Because diary data is the participant's estimate of actual sleep, and thus may not be completely accurate, FRA decided to collect sleep and work data from a group of locomotive engineers

[11] Surface Transportation Board Statement A-300 for 2010. Downloaded from www.stb.dot.gov.

using actigraphy for the sleep data and a logbook for the work data. (Actigraphy is a technique for recording sleep and wake periods through a wrist-worn device about the size of a wrist watch.) A total of 46 locomotive engineers participated and data from 41 were usable for the purposes of the study.

With the baseline AutoSleep settings, AutoSleep and the actigraphy agreed 85 percent of the time, but the distribution of sleep across the day was statistically different. When the baseline settings were adjusted to reflect a slightly later bedtime, a shorter "forbidden zone" when sleep may not occur, and more sleep on rest days, agreement rose to 87 percent. With the adjusted AutoSleep settings, the distribution of sleep periods across the day was no longer statistically different from that of the actigraphy data. A complete description of this validation study is available in Gertler, Hursh, Fanzone, and Raslear (2012).

The above finding demonstrates that fatigue assessments of railroad work schedules using FAST are based on valid expectations of average sleep patterns and, therefore, provide a reasonable estimate of sleep restriction and associated fatigue risk.

4.4 Sleep and Fatigue

As noted previously, SAFTE and FAST contain two processes that are involved in modeling fatigue: a sleep reservoir and a circadian oscillator. This fatigue model can be expressed as

$$\text{Fatigue} = f(\text{sleep} + \text{circadian rhythm})$$

In a previous report (Hursh *et al.*, 2008) it was determined that the correlation (r) between human factor accident risk and FAST scores was -0.93, which means that the FAST score (fatigue) accounted for 86 percent of the variance (percent variance accounted = r^2 x 100) in human factor accident risk. The same report also examined the risk of a human factor accident as a function of the TOD of the accident to assess the contribution of the circadian oscillator to risk. The correlation of human factor accident risk and TOD was 0.71, indicating that the circadian oscillator accounted for 51 percent of the variance in human factor accident risk. Consequently, a simple additive model of variance suggests that sleep duration should account for approximately 35 percent (86 – 51) of the variance in FAST scores. Table 25 shows the correlations between FAST score, primary sleep, total sleep, and sleep periods for the 12 work schedule types on work days and rest days (N = 12 x 2).

Table 25. Correlation of FAST with Sleep Duration and Sleep Periods

	Primary Sleep	Total Sleep	Sleep Periods
Correlation (r)	0.657	0.586	0.019
t-test *p*-value	0.000	0.001	0.464
N	24	24	24

As expected, FAST is reliably correlated with the duration of primary sleep and total sleep, but not with number of sleep periods. Primary sleep accounts for 43 percent of FAST score variance, and total sleep accounts for 34 percent, which is consistent with the expectation, based on the scientific literature, that fatigue is a function of sleep and circadian influences. Sleep duration is obviously an important aspect of fatigue exposure and risk, but it is not the only factor. Circadian rhythms must also be considered, and this is the true value of biomathematical models in fatigue management: they allow for easy evaluation of the interaction of multiple processes.

4.5 Summary

FAST was used to analyze the work schedules and sleep data collected from each of the five studies and to calculate the exposure of each group to fatigue. The two groups with the most fatigue exposure were T&E and dispatchers. Both groups work around the clock. In contrast, passenger T&E workers, who also work around the clock, had the least exposure to fatigue. Differences in sleep patterns arising from the predictability of passenger T&E work schedules can explain this. Passenger T&E workers have highly predictable work schedules and can plan sufficient sleep to avoid fatigue. The lack of predictable work schedules in T&E prevents such planning even though both groups have similar work schedule patterns.

Employees involved in human factors accidents had more average exposure to fatigue than any of the five employee groups. Fatigue, as measured by FAST, was significantly correlated with primary and total daily sleep. Sleep duration accounted for 34 – 45 percent of the variance in fatigue. Circadian rhythms are known to account for 51 percent of the variance in fatigue in human factor accidents. Since fatigue accounts for 86 percent of the variance in human factor accident risk, it is clear that sleep and circadian rhythms are key factors in understanding fatigue exposure, although other factors can account for 14 percent (4–15 percent) of the remaining variance.

5. Fatigue Risk and Accidents

As noted in Section 4, the FAST model has been validated using railroad accident data. To reiterate, Hursh *et al.* (2006, 2008) showed that there was a statistically reliable relationship between effectiveness and the risk of a human factors accident. By contrast, there was no relationship between effectiveness and the risk of a nonhuman factor accident. Hursh *et al.* also determined the level of effectiveness at which cumulative risk of a human factor accident was statistically greater than both chance (risk = 1) and mean risk of a nonhuman factor accident (risk = 1.04). That level of effectiveness was ≤ 70, which is the FRA fatigue threshold in 49 C.F.R. § 228. The regulation defines the fatigue threshold as a level of fatigue at which safety may be compromised. Table 18 provides the basis for indicating that safety may be compromised at effectiveness ≤ 70: the risk of a human factors accident is elevated 21 percent—65 percent above chance. Table 18 also indicates that at effectiveness > 90, human factor accident risk is significantly decreased (16 percent below chance). Essentially, the data in Table 18 provide the basis for calibration of FAST, and this is reflected in the nomenclature described in Table 21. General procedures for validating and calibrating human fatigue models can be found in Tabak and Raslear (2010) and Raslear (2011). A validated and calibrated model of human fatigue has many uses, including the prediction of fatigue-related accident risk. This section examines the relationship between fatigue exposure and human factor accident risk.

5.1 Fatigue–related Accident Risk and Accident Probability

Transitioning a theoretical model of fatigue (e,g., SAFTE) to operational use requires several steps, including deriving a fatigue scale and calibrating such a scale to accident risk or similar operational data (Raslear, Hursh, and Van Dongen, 2011). Risk, however, has a number of different meanings and definitions. In the social sciences, risk is often conceptualized as a set of probabilities associated with decision outcomes (Krantz, Luce, Suppes, and Tversky, 1971, p. 124). In statistics, outcomes in a joint distribution that deviate from the expected values (as determined by the products of marginal values) suggest an association between the variables (Hays, 1963), which can be interpreted as risk in the probabilistic sense (i.e., variable Y is more probable as variable X increases or decreases). In epidemiology, risk is a deviation of event rates in a population with a risk factor relative to event rates in a population without that risk factor (Lilienfeld and Lilienfeld, 1980). Finally, in engineering, risk is defined as a collection of pairs of likelihoods and costs (Kumamoto and Henley, 1996). A common engineering definition of risk is the product of probability and cost. Risk in this view is the expected value.

The epidemiological and statistical definitions of risk are often called relative risk because the risk is calculated relative to some alternative. In the Hursh *et al*. (2006, 2008) study, the statistical approach was taken since risk was defined as the ratio of the proportion of accidents at an effectiveness level to the proportion of work time at that effectiveness level:

$$\text{Risk Ratio} = \frac{(\mathit{Accidents\ at\ Effectiveness\ Level})/(\mathit{Total\ Number\ of\ Accidents})}{(\mathit{Work\ Time\ at\ Effectiveness\ Level})/(\mathit{Total\ Work\ Time})}. \qquad (1)$$

In this approach, accident risk due to fatigue is defined by comparison to fatigue exposure (work time). If accident risk is not influenced by fatigue, a plot of risk as a function of effectiveness should be a line with a slope of zero. Figure 34 shows accident risk as a function of

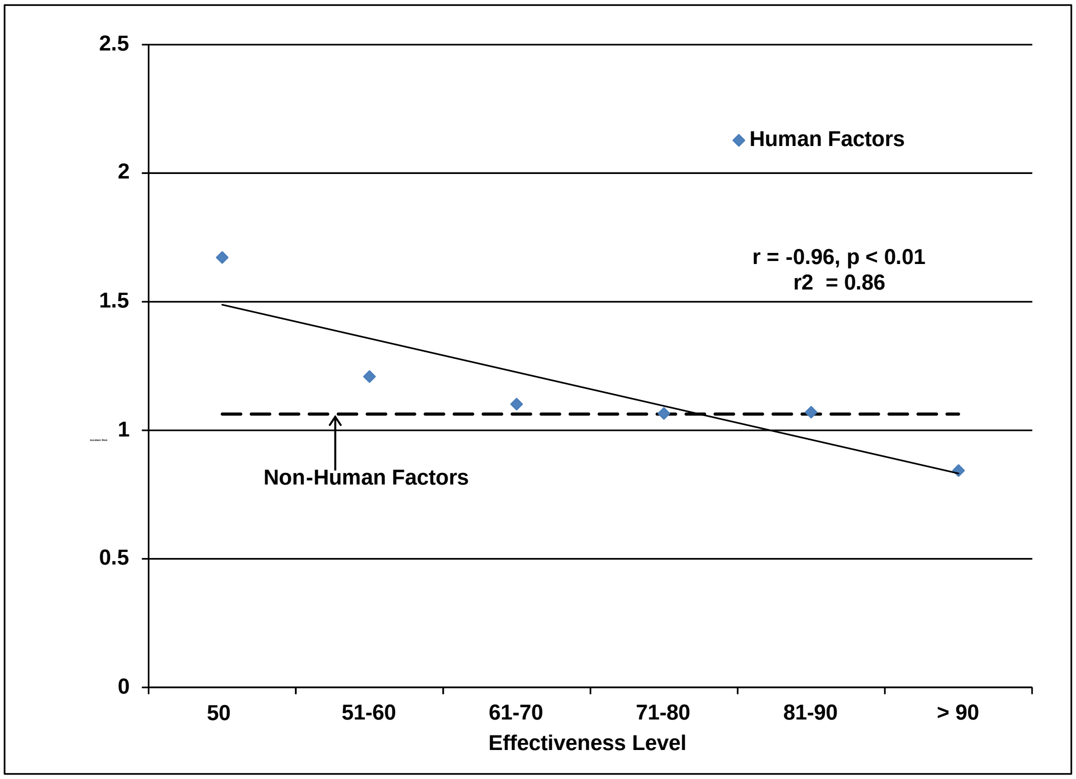

Figure 34. Human Factors Accident Risk (defined statistically) as a Function of Effectiveness

effectiveness from the Hursh *et al*. (2006, 2008) reports. While human factor accidents show a reliable increase in risk as a function of effectiveness level, non-human factor (NHF) accidents do not. The mean risk for NHF accidents indicates that a line with zero slope is an adequate representation of the NHF accident data.

By contrast, accident risk in epidemiology is defined by the rate of accidents in effectiveness levels with fatigue relative to the rate of accidents in effectiveness levels without fatigue:

$$Risk = \frac{Accident\ Rate\ in\ Effectiveness \leq 90}{Accident\ Rate\ in\ Effectiveness > 90} \qquad (2)$$

Here, accident rate is the number of accidents at an effectiveness level divided by the number of hours working at that effectiveness level. Figure 35 shows a result similar to Figure 34. There is a statistically reliable linear relationship between accident risk and effectiveness level for human factors accidents. The slope of the line for NHF accidents as a function of effectiveness was not statistically different from zero. The two measures of risk differ slightly, as expected, but lead to the same conclusions: human factor accidents are more likely when there is more exposure to fatigue, but fatigue does not have a similar effect on non-human factors accidents. However, these two approaches do not indicate what the actual probability of a human factor accident is, given a particular effectiveness level [$p(HFA|E_x)$]. $p(HFA|E_x)$ is the conditional probability of a HFA given fatigue at effectiveness level x. In the engineering approach, the probability and the cost constitute risk. The Hursh *et al*. (2011) report provides important information about fatigue and the cost of HFA, but not about $p(HFA|E_x)$.

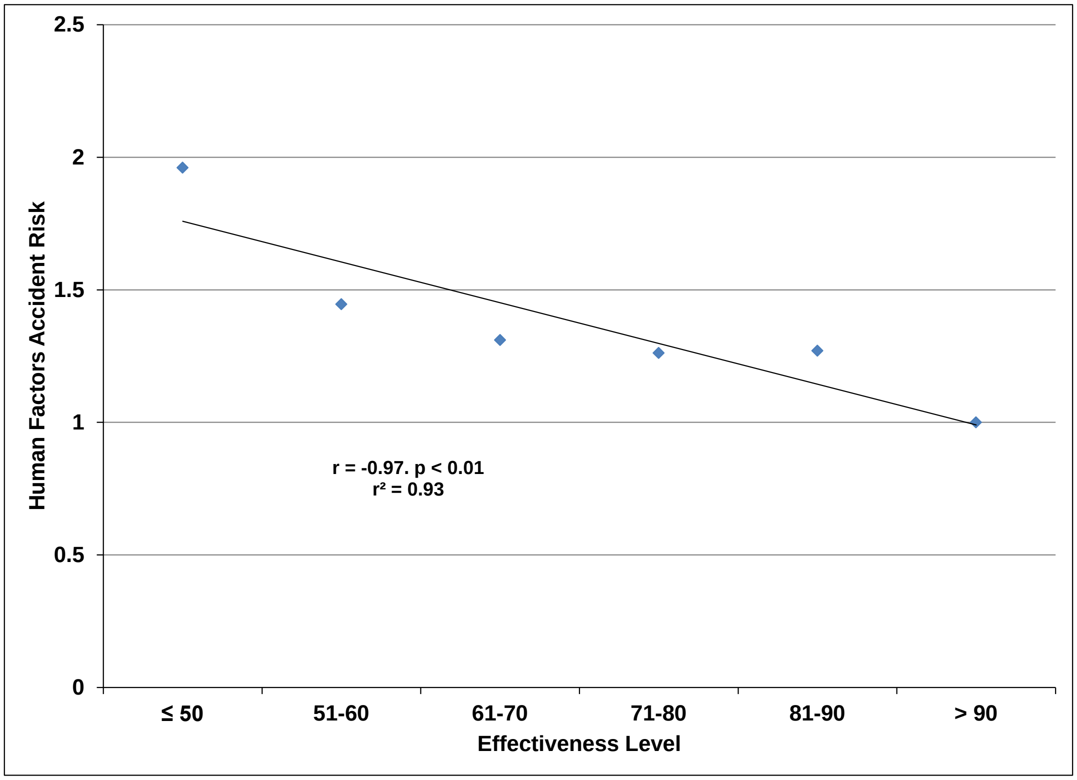

Figure 35. Human Factors Accident Risk (defined epidemiologically) as a Function of Effectiveness Level

Accidents are rare, random events that are often modeled as probabilities using the Poisson distribution (Parzen, 1960). The Poisson distribution describes the relationship between periods of time and the probability that a certain number of accidents will occur in that period of time. The probability that exactly k events occur in a time period of length t is given by

$$p = e^{-\mu t}\left(\frac{\mu t^{k}}{k!}\right), \tag{3}$$

where μ is the mean rate of events per unit time, t. The probability that one or more events will occur is $1 - e^{-\mu t}$. To estimate $p(HFA|E_x)$, one needs to know the frequency of HFA at various levels of effectiveness and the number of employee-hours (e-h) exposure at each level of fatigue.

5.2 Fatigue and Human Factors Accidents

Figure 31 (p. 54) shows the proportion of work time as a function of effectiveness in three bins (≤ 70: very fatigued, ≤90: fatigued, and > 90: not fatigued) for accidents, signalmen, MOW workers, dispatchers, T&E crews, and passenger T&E crews. This is a profile of fatigue exposure or probability. Workers involved in accidents spend the most work time in fatigued conditions and the least work time not fatigued. In other words, they have the most fatigue exposure. Fatigue exposure is necessary to calculate risk and accident probability. Although fatigue exposure is known for accidents and for the five work groups shown in

Figure 31, the frequency of HFAs as a function of effectiveness is only known for accidents. While accident risk and accident probability can only be determined for accidents at this time, fatigue exposure is an important precursor to HFA and must be managed to prevent accidents.

The calculation of p(HFA|E) is shown in Table 26. The number of HFA attributed to locomotive crews (locomotive engineers and conductors) from January 2003 to June 2005 as a function of effectiveness (E) is shown (see Hursh *et al*, 2006, 2008 for details). The table also shows the estimated proportion of work time for each effectiveness level based on 790 employees. Total e-h for the same railroads were obtained from the FRA database for the same time period. More than 749 million e-h were worked at these railroads. The e-h data were partitioned into fatigue levels using the proportion of work time data in the table. The frequency of accidents and e-h at each fatigue level was used to calculate a value of μ for equation (3), from which the probability of one or more HFA per 200,000 e-h was obtained[12]. Table 26 shows that, in the absence of fatigue, the probability of one or more HFA is 0.15. As fatigue increases, the probability of a HFA increases to 0.27. At the fatigue threshold (≤ 70), the probability of a HFA is about 0.19.

To illustrate the validity of this approach to calculating probabilities, the same method can be used to predict the number of days in 2004 for which there were 0, 1, 2, or 3 human factor caused collisions on all types of track for BNSF, UP, CSX, KCS and NS. The rate of HFA per day (μ) is 182/366 = 0.497. The prediction (using equation (3)) is shown in Figure 36 along with the data from the FRA database. The Poisson prediction is that 223 d would have no accidents.

Table 26. Human Factor Accidents, Proportion of Work Time, E-H, Human Factors Accidents per E-H, and Probability of Human Factor Accidents, as a Function of Performance Effectiveness Predicted by the SAFTE model

Effectiveness Level (inverse of fatigue)	**≤50** (severely fatigued)	**>50–60** (extremely fatigued)	**>60–70** (very fatigued)	**>70–80** (moderately fatigued)	**>80–90** (fatigued)	**>90** (not fatigued)
Human Factor Accidents (HFA)	33	38	95	123	183	259
Proportion of Work Time	0.027	0.043	0.118	0.158	0.234	0.420
E-H	20,457,144	31,961,042	88,125,804	118,489,773	175,186,642	314,829,738
HFA per E-H (μ)	$1.61 \cdot 10^{-6}$	$1.19 \cdot 10^{-6}$	$1.08 \cdot 10^{-6}$	$1.04 \cdot 10^{-6}$	$1.04 \cdot 10^{-6}$	$0.82 \cdot 10^{-6}$
Probability of ≥1 HFA per 200,000 e-h	0.276	0.212	0.194	0.188	0.189	0.152

There were 230 d in 2004 on which no accidents of the type described were observed. A χ^2 test of the observed and predicted frequencies showed no reliable difference, χ^2 (3, N = 366) = 5.12, $p > 0.05$.

[12] 200,000 e-h is a standard exposure metric for occupational accidents. This is the e-h for 100 employees working 40 h/week for 50 weeks.

Given p(HFA|E), the calculation of engineering risk only requires information about the cost of HFA for various effectiveness levels. As noted above, Hursh *et al.* (2011) have information on the cost of HFA. Figure 37 shows the average cost of a HFA. Accidents involving fatigue have much higher associated costs than accidents where there is no fatigue ($E > 90$). When $71 \le E \le 90$, average cost is double the cost with no fatigue ($E > 90$). When $E \le 70$, the average cost is four times the cost with no fatigue. Figure 38 shows accident risk (p(HFA|E) x cost). Risk accelerates even more quickly than cost as a function of E. When $71 \le E \le 90$, risk is nearly 2.5 times the cost with no fatigue. When $E \le 70$, average cost is 5.1 times the cost with no fatigue.

Regardless of the method used to determine the accident risk of fatigue, it is clear that fatigue increases the risk of HFAs and that more fatigue results in more risk. When the engineering approach is taken, risk increases exponentially with fatigue. Fatigue exposure is an important determinant of fatigue risk. Groups of railroad workers with the highest exposure to fatigue are T&E crews and dispatchers. These two groups, as a whole, have considerably less fatigue exposure than T&E crews who were involved in accidents. The analyses by Hursh *et al.* (2006, 2008) indicate that a critical exposure level occurs when $E \le 70$ for 20 percent or more of work time. None of the five railroad occupations reaches this level as a group. However, third shift dispatchers have 31.5 percent of work time at $E \le 70$. Moreover, as Table 22 shows, many other subgroups of employees have a fatigue exposure at $E \le 90$, exceeding or approximating that of workers who had accidents. This suggests that fatigue management for these subgroups could further reduce fatigue caused HFA and be economically beneficial.

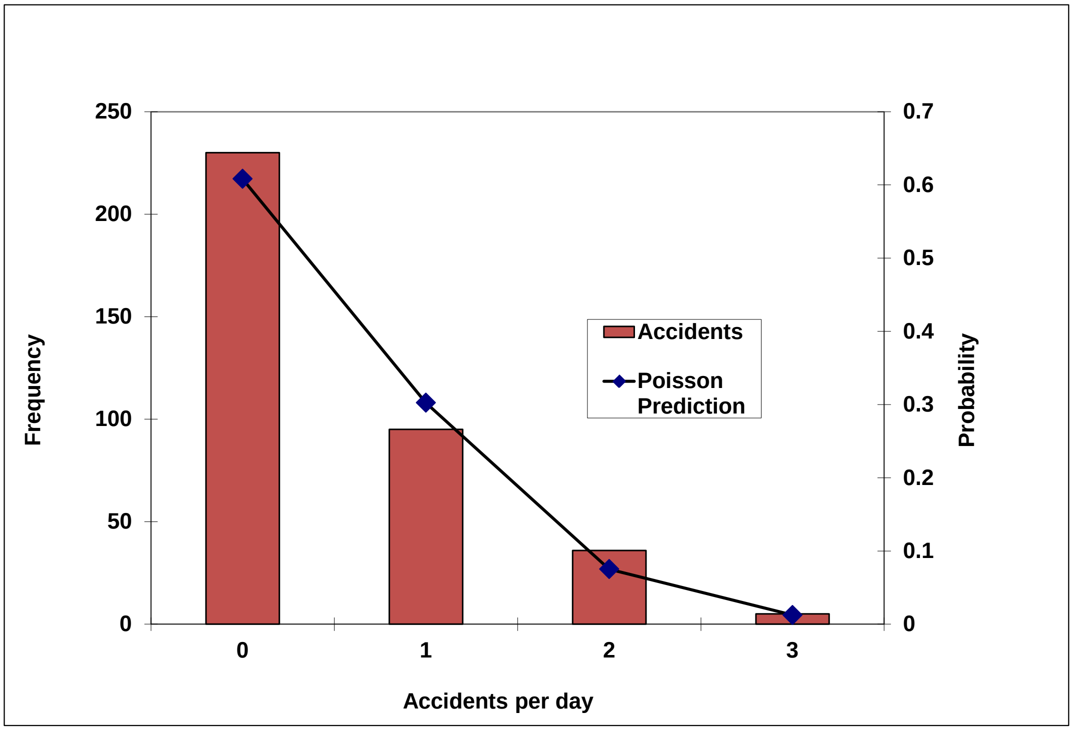

Figure 36. Observed Human Factor Caused Collisions per Day in 2004 for Five Railroads and the Prediction from the Poisson Probability Law

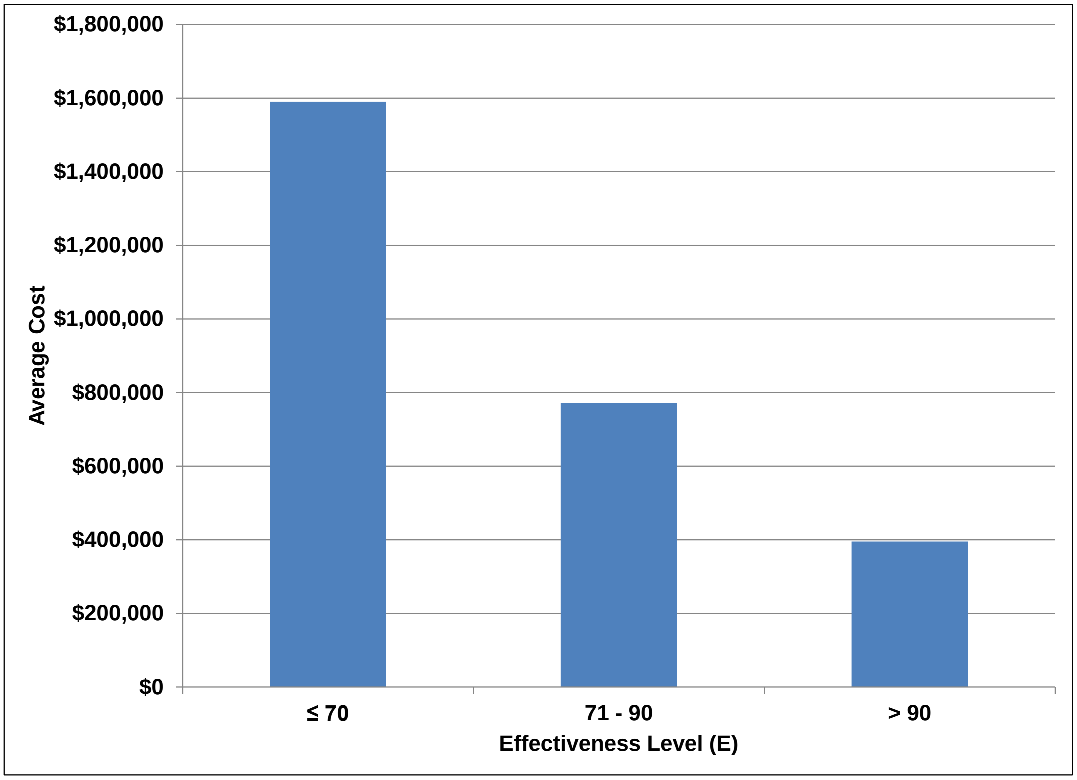

Figure 37. Average Cost of a HFA as a Function of Effectiveness Level (E)

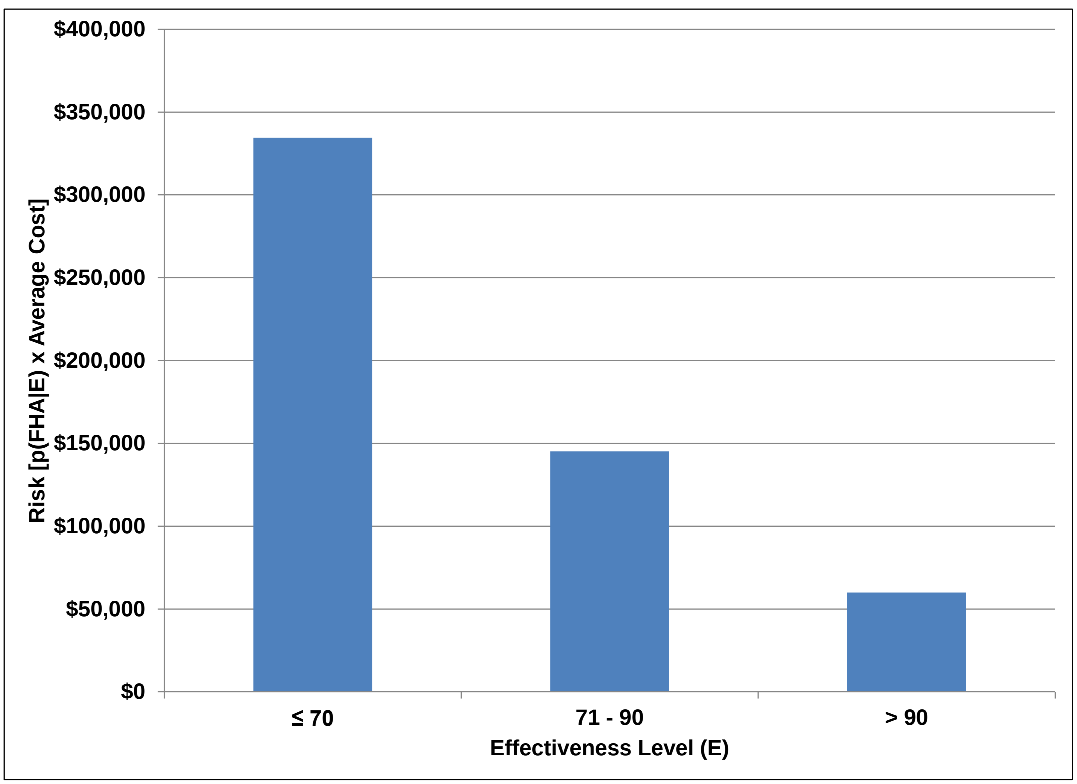

Figure 38. Risk of Human Factor Accident as Function of Effectiveness Level (E). Risk Determined from Probabilities in Table 26 and Average Costs in Figure 37.

5.3 Summary

The statistically defined risk of a human factors accident is elevated 11 to 65 percent above chance by exposure to fatigue. In the absence of fatigue, human factor accident risk is below chance by 16 percent. Risk can also be defined as the product of a probability and an economic consequence. The probability of a human factor accident given a level of fatigue can be estimated using Poisson distribution. In the absence of fatigue, the probability is 0.15. If an employee is very fatigued, the probability increases to 0.19. The economic cost of a human factors accident when an employee is very fatigued is approximately $1,600,000, compared to $400,000 in the absence of fatigue. Thus, the risk of a human factor accident for a very fatigued employee is 5.1 times the risk with no fatigue [(0.19 x $1,600,000)/(0.15 x $400,000)].

6. Findings, Implications, and Future Directions

Over the past 20 years, FRA has conducted significant research on work schedule-related fatigue. The research had three major focuses: characterization of work schedules and sleep patterns of four groups and one subgroup of railroad workers, validation of a biomathematical model for predicting fatigue of railroad workers, and proof of a relationship between fatigue and railroad accidents. The key findings of this work are as follows:

- Sleep and circadian rhythms account for 85 to 96 percent of the variance in fatigue exposure, which is consistent with the current view of fatigue. Because circadian rhythms are endogenous, they are difficult to change. A focus on increasing sleep duration and quality is, consequently, an obvious approach to reducing fatigue. However, the factors associated with the remaining 4 to 15 percent of the variance remain to be identified and used to manage fatigue.
- Dispatchers and T&E workers have work schedules that include night work which gives them the most exposure to fatigue. MOW and signalmen, who work primarily during the day, have some exposure to fatigue because of emergency calls which occur at night. Passenger T&E workers have a pattern of work that is similar to that of the T&E group, but have the least exposure to fatigue. The primary difference between the passenger T&E and the T&E groups is the predictability of work. Passenger T&E work schedules are highly predictable, whereas the T&E work schedules are not. The predictability of work allows passenger T&E workers to plan sleep better to avoid fatigue. This suggests that improving the predictability of work schedules is one way to reduce fatigue exposure in the railroad industry.
- In addition to being the most at risk of fatigue, T&E workers are also the group that works the most hours and is most likely to exceed the RSIA statutory limit of 276 h in a calendar month. Since the largest group of railroad employees is in the T&E crafts, the total number of hours at risk is substantial.
- The sleep pattern of railroad workers differs from that of U.S. working adults. Railroad workers are more likely to get less than 7 h of total sleep on workdays, which potentially puts them at risk of fatigue, but railroad workers, on average, obtain more total sleep than U.S. working adults.
- Based on the T&E survey results, an opportunity exists for the railroads to provide more fatigue education as part of a fatigue risk management program.
- Railroad workers report sleep disorders and sleep apnea at a higher rate than is believed to be present among U.S. working adults. A railroad fatigue education program should emphasize the symptoms of sleep apnea and other sleep disorders and encourage employees to be evaluated and treated if they exhibit those symptoms.
- Railroad workers involved in human factors accidents have a higher exposure to fatigue than any of the railroad worker groups examined.
- Human factor accident probability increases with fatigue exposure. At FAST score <70, it is increased by 28 percent. The cost of human factor accidents increases with fatigue exposure. At FAST score <70, cost is increased by almost 200 percent. The risk

(probability X cost) of a human factors accident increases with fatigue exposure. At FAST score < 70, risk is increased by almost 500 percent.

- A consistent methodology has been developed for studying the work schedules and sleep patterns of railroad workers. This methodology allows for the collection of data which makes it possible to identify differences in sleep patterns as a function of both work group and work schedule. Furthermore, these data provide input to the SAFTE-FAST model for evaluating fatigue risk.

Future fatigue research should focus on assessing the changes that occurred following the passage of the RSIA. The results presented in this report provide a baseline for assessing/analyzing railroad industry fatigue risk prior to changes in HOS. These changes affected only T&E and signalmen so perhaps priority should be given to those two groups; focus could subsequently be shifted to MOW and dispatchers. When conducting a follow-up study, researchers should consider surveying all employee groups simultaneously by employing a stratified sample. Such an approach would minimize the effort required to both secure OMB approval and administer the survey. Another potential research area involves identification of factors associated with the unexplained portion of variance in fatigue exposure. These factors might include nutrition and use of over-the-counter drugs, as well as individual differences.

While changes in the work hours of MOW and dispatchers will not change due to regulation, it is possible that some railroad practices or labor agreements for these groups will be modified to reduce fatigue risk. At a minimum, any fatigue education that is part of a railroad's fatigue risk management program will apply to these groups, as well as T&E and signalmen. Individual railroads can use the results summarized in this report to identify potentially at-risk groups when they develop fatigue risk management plans.

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Abbreviations and Acronyms

ANOVA	Analysis of Variance
BAC	blood alcohol concentration
CDF	cumulative distribution function
d	day(s)
DOD	Department of Defense
E	effectiveness
e-h	employee-hours
FAID	Fatigue Audit Interdyne
FAST	Fatigue Avoidance Scheduling Tool
h	hour(s)
HFA	human factors accident
HOS	hours of service laws
min	minute(s)
MOW	maintenance of way
NHF	non-human factors
OMB	Office of Management and Budget
r	correlation
SAFTE	Sleep, Activity, Fatigue and Task Effectiveness
T&E	train and engine service
TOD	time of day