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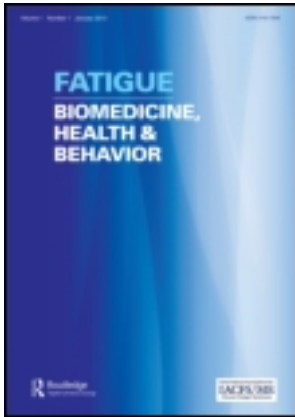
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## Work schedules, sleep, fatigue, and accidents in the US railroad industry

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**Objective:** The objective of this report is to provide a comprehensive description of fatigue in US railroad workers employed in safety-sensitive positions. **Methods:** Five survey studies were conducted between 2006 and 2011 on maintenance of way employees, signalmen, dispatchers, train & engine (T&E) employees, and T&E employees engaged in passenger service. These studies were reanalyzed and compared with regard to work schedules and sleep patterns. Fatigue exposure was determined by analysis of work schedules and sleep patterns with a fatigue model, the Fatigue Avoidance Scheduling Tool (FAST). **Results:** Twelve different schedules of work exist in the five groups of railroad employees. Work schedules largely determine sleep patterns, which, in turn, determine fatigue exposure. T&E crews and dispatchers have the highest fatigue exposure, but these two groups have considerably less fatigue exposure than T&E crews who were involved in accidents. Passenger service T&E employees have the least fatigue exposure, even though the distribution of work time is highly similar to that of T&E employees. This difference in fatigue exposure may be due to the greater predictability of work for the passenger service T&E. Human factor accident probability and the cost of human factor accidents increase with fatigue exposure. The risk (probability  $\times$  cost) of a human factor accident increases exponentially with fatigue exposure. **Conclusions:** A 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. Future work on fatigue in occupational groups should focus on similar methods to expand our knowledge of the role of work schedules on sleep, fatigue, and accident risk.

**Keywords:** fatigue; sleep; accidents; work schedules; railroads

### Introduction

The objective of this report is to provide the first comprehensive description of fatigue in US railroad workers employed in safety-sensitive positions. Early consideration of fatigue and alertness, and its role in accident causation, was limited to linking work hours to fatigue. Federal laws governing railroad employees' hours of service began with the enactment of the Hours of Service Act of 1907 [1] and were subsequently

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repealed and recodified (see the Hours of Service Act of 1994 [2]). These laws, collectively referred to in this paper as the Hours of Service Law (HOS Law), are intended to promote safe railroad operations by limiting the hours of service of three categories of railroad employees (signalmen, dispatchers, and train & engine (T&E) service employees) and by ensuring that these employees receive adequate opportunities for rest in the course of performing their duties. However, statutory or regulatory limitations on hours of work may not be sufficient to prevent worker fatigue.

Until recently, HOS rules totally ignored circadian influences in fatigue, and Federal Railroad Administration (FRA) accident data (the FRA accident database and a description of the database can be found at <http://safetydata.fra.dot.gov/officeofsafety/default.aspx>) did not provide information to show that fatigue was a major cause of railroad accidents. The FRA accident cause code, "Employee Asleep" (H104), is the only accident code related to fatigue. Very few accidents (0–8% out of 2000) to the present time have a fatigue cause code, and this, in turn, can be taken as evidence that fatigue is not a safety problem in the railroad industry. However, anecdotal information (mainly complaints from labor) has suggested that fatigue is an important safety concern. Moreover, the National Transportation Safety Board (NTSB) had investigated several railroad accidents and concluded that fatigue was a contributing cause (e.g., [3,4]).

Ultimately, NTSB added fatigue to its Most Wanted List of safety issues. 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. To do this the Federal Railroad Administration (FRA) has sponsored work/rest surveys of T&E crews and other railroad worker groups.[5–9] FRA has also supported the development of a biomathematical model, the Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model, to analyze work schedules for fatigue risk. FRA has used the Fatigue Avoidance Scheduling Tool (FAST), a software instantiation of the SAFTE model, to assess the risk of fatigue-related railroad accidents.[10–12]

The research described in this report was conducted prior to the changes in the HOS rules mandated by the passage of the Railroad Safety Improvement Act of 2008 (RSIA) [13] and should provide a baseline for evaluating the effect of HOS rule changes on fatigue in the railroad industry. The paper is organized around the premise, common to most models of fatigue, that sleep and circadian rhythms are the primary determinants of fatigue.[14]

Because work schedules determine when sleep can occur, the primary characteristics of work schedules are described for five work groups: signalmen, maintenance-of-way employees (MOW), dispatchers, T&E crews, and passenger service T&E crews. Sleep patterns are described in relation to work duration, work time of day, and schedule variability/predictability. Fatigue exposure is largely determined by sleep patterns and work schedules [15,16] and is assessed by the FAST model. The probability of a human factor accident given fatigue [ $p(\text{HFA}|\text{fatigue})$ ] is determined by fatigue exposure. Human factor accident (HFA) risk is described as the product of  $p(\text{HFA}|\text{fatigue})$  and the cost of a HFA given fatigue.

## Methods

Five survey studies [5–9] were conducted using the same overall approach. Because each survey involved more than nine participants, Federal regulations required that the Office of Management and Budget (OMB) approve the study design for each

survey. The potential respondent universe for each study consisted of the actively working members of the unions representing that employee group (signalmen, MOW, dispatchers, T&E, passenger service T&E). A random sample of the potential respondents was drawn, determined by the size of the potential respondent universe, acceptable error tolerance (15%), and desired reliability (95% confidence level) of the results in accordance with standard practice.[17] A non-response bias study validated that no difference existed between the survey participants and the non-respondents. For all surveys, age was the basis for the non-response bias analysis. A total of 1573 (36.16% response rate) railroad employees participated in the surveys (signalmen, 388; MOW, 252; dispatchers, 443; T&E, 250; passenger service T&E, 240).

Each person in the random sample received two study instruments: a background survey and a 14-day daily activity/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. Additional information about the surveys may be found in the original reports.[5–9] The survey materials and databases are in the public domain and can be obtained at <http://www.fra.dot.gov/Page/P0604>.

FAST, a software tool for analyzing work,[18] was used to determine fatigue exposure based on the work and sleep patterns of each respondent in each half hour of the 14 days of the daily activity/sleep log. By combining these results for all work periods and all individuals in a specific work group, descriptive statistics such as means, standard deviations, and cumulative distributions of the proportion of work time spent at a fatigue exposure level were created. Table 1 shows FAST scores based on a person who has eight hours of sleep, wakes at 7 am, and remains awake for the amount of time indicated. A FAST score of >90 indicates a well-rested individual (someone who has had eight hours of sleep, awakening at 7 am, and has been awake for 16 hours or less). A FAST score of 70 indicates a high level of fatigue: the person has been awake for 21 hours, performs on standard lab tests, such as the psychomotor vigilance test, equivalent to someone who has a 0.08 blood alcohol concentration, and

Table 1. FAST score, lapse likelihood, hours awake, and equivalent blood alcohol concentration (BAC) (after [10,11]).

FAST score	Lapse likelihood	Hours awake (h: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	

has a five-fold increase in lapses (an excessively long reaction time or failure to detect a critical event caused by a microsleep or loss of alertness).

## Results

### *Work schedules*

Work schedules were analyzed as to type of work schedule, work duration, time of day of work, and work schedule variability. Table 2 provides an overview of the different types of work schedules of signalmen, MOW, dispatchers, T&E, and passenger T&E. There are 12 different types of work schedules: four days per week, five days per week, eight days on/six days off, first shift, second shift, third shift, relief, extra board, fixed start time, variable start time, straight through assignments, and split shift assignments. The HOS Law covers all but the MOW workers. RSIA did not make changes to HOS for dispatchers. Consequently, dispatchers and MOW workers become a natural control group for any future study of the effects of regulations implemented after RSIA. Signalmen and MOW workers work primarily for eight hours 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.

To meet the need for 24-hour operation, railroads staff their dispatching center with three eight-hour shifts. Typical shifts are 7 am to 3 pm (day), 3 pm to 11 pm (evening), and 11 pm to 7 am (night). Three categories of jobs exist in all dispatching centers: regular jobs, relief jobs, and extra board jobs. Regular jobs work five consecutive days on the same shift followed by two consecutive days off. Relief jobs work five consecutive days by rotating through the shifts, in a pattern such as two days, two evenings, and one 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.

Table 2. Types of work schedules by group.

Employee group	Work schedules	Covered by HOS Law?
Signalmen	Four days per week Five days per week	Yes
MOW	Eight days on/six days off Four days per week Five days per week	No
Dispatchers	Eight days on/six days off First shift Second shift Third shift Relief Extra board	Yes, except Chief Dispatcher
T&E	Fixed start time Variable start time	Yes
Passenger T&E	Extra board Straight thru assignment Split assignment Extra board	Yes

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 five days of work per week, but the days and shifts that they work may change weekly. In addition, extra board dispatchers usually do not have two consecutive rest days. The dispatcher may not remain on duty for more than nine hours, 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 nine hours, he/she must have 15 hours of rest. Where only one shift is employed, the dispatcher may remain on duty for up to 12 hours in any 24-hour period. During an emergency situation, the law allows the dispatcher to remain on duty for an additional four hours in any 24-hour period for a maximum of three days over the course of seven days. This 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.

The work schedules 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 for 24 hours a day, railroads staff their yards with either three eight-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 four hours, 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 that 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.

Average duration of work in two 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 1 contains distributions of the work start and end times for each of the groups.

Signalmen and MOW workers have similar schedules with daytime starts. T&E and passenger T&E have work starts and ends spread throughout the day with passenger having more work starts during the daytime. Dispatchers work three distinct shifts. A goodness of fit  $\chi^2$  analysis of the start and end times for each of the five groups confirmed that none follow a uniform distribution; all  $\chi^2$  analyses had  $p < 0.05$ . This means that for each group there are definite times of day when work starts and ends are more



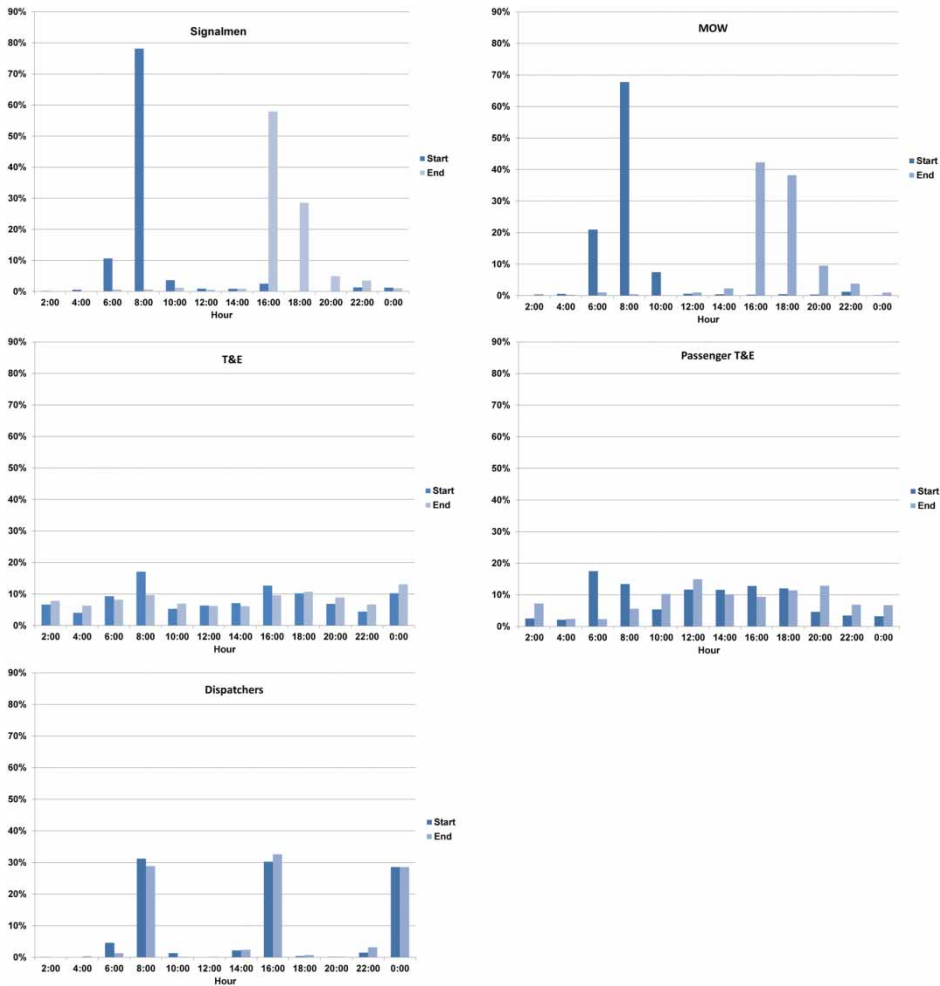


Figure 1. Work start and end times by group.

likely. Railroading is a round-the-clock, seven-days-a-week operation, but operations are not uniform through 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.

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 an hour from the previous day was the definition for start time variability (STV).

For the signalmen, 10% of construction signalmen (mean STV = 0.23 h) and 37% of non-construction signalmen (mean STV = 0.5 h) had one or more instances of STV during the two-week timeframe of the study. The relationship between STV and job type was statistically significant,  $\chi^2(4, N = 389) = 26.93, p < 0.05$ ; STV is not independent of job type. The higher level of variability in non-construction signalmen's schedules was likely due to their need to respond to emergencies.



Start time variability for MOW workers was similar to that of the signalmen. For those working a production job, similar to a construction signalman, 16% had at least one instance of STV (mean = 1.02 h) and 22% of non-production MOW workers experienced STV (mean = 1.5 h) at least once. This difference between job types was not statistically significant,  $\chi^2(4, N = 254) = 5.21, p = 0.267$ .

For dispatchers, schedule variability applies to only those working relief jobs and the extra board. Nearly 70% of the participants in the dispatcher study worked the same shift each day (mean STV = 0.25 h). The remainder was split between relief (19%, mean STV = 3.03 h) and extra board (12%, mean STV = 1.68 h). 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.

STV 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 STV, and this has been a major contributor to their fatigue issues. Even those working jobs with a fixed start time had a mean STV of 3.3 hours. T&E workers on jobs with variable start times had a mean STV of 7.1 hours and a quarter of these jobs had a STV of nearly nine hours. There was much less schedule variability for the T&E workers in passenger service (mean STV = 1.1 h).

### *Sleep patterns*

Work schedules provide sleep opportunities but do not exclusively determine the amount of sleep that is obtained. Sleep data across work groups were combined to examine how sleep varies by comparable types of schedules. Table 2 shows the 12 types of schedules used for this analysis (four days per week, five days per week, eight days on/six days off, first shift, second shift, third shift, relief, extra board, fixed start time, variable start time, straight through assignment, split assignment). Daily primary sleep, total daily sleep, and the average number of sleep periods were examined separately with one-way ANOVAs. Daily primary sleep for a given calendar day is the longest sleep period ending on that day. Total daily sleep is primary sleep plus any supplementary sleep periods (naps) or the sum of all sleep periods that end on a calendar day. 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 employees' sleep is segmented, which can result in fatigue if sleep periods are not sufficient to allow individuals to adequately cycle through the typical stages of sleep.

The 12 schedule types 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 ( $F(11, 1573) = 14.75, p < 0.0001$ ). Figures 2 and 3 show that third shift and relief schedules obtain the least amount of both primary and total daily sleep, while split and straight assignment employees obtain the most amount of primary and total daily sleep of the schedule types. Interestingly, employees working third shift, relief, and split assignments report the highest number of daily sleep periods (Figure 4). However, third shift and relief employees do not approach the total amounts of daily sleep that split assignment workers are able to obtain.

The total daily sleep for each work group was compared with total daily sleep from the National Sleep Foundation.[19] Total daily sleep distributions for each railroad employee group differed significantly from the NSF data for US adults for workdays

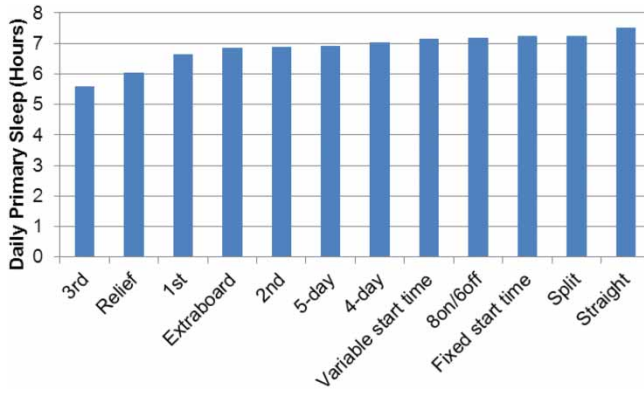


Figure 2. Daily primary sleep (hours) by type of schedule.

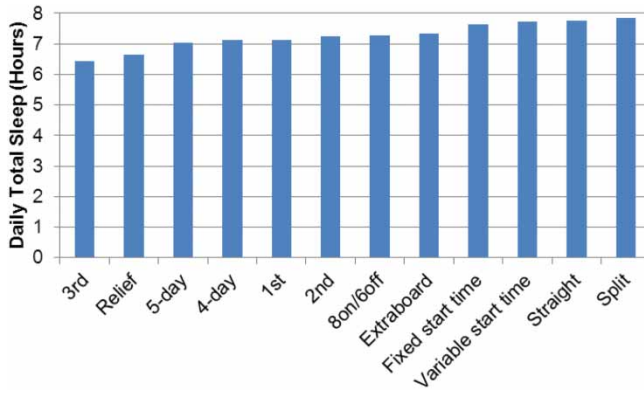


Figure 3. Total daily sleep (hours) by type of schedule.

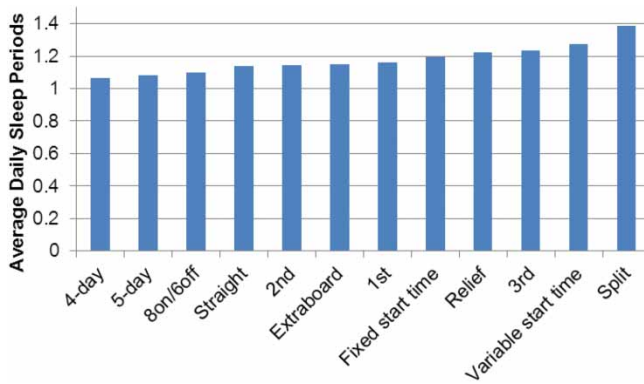


Figure 4. Average daily sleep periods by type of schedule.

(Table 3). The mean workday sleep for all groups exceeded that of US adults on workdays (sign test, one-tailed,  $p < 0.05$ ), but the railroad workers as a group had a greater proportion of sleep under seven hours (0.52 vs. 0.46,  $z = 3.25$ ,  $p < 0.001$ ).

**Fatigue exposure**

The work and sleep data from each of the five sets of survey data were analyzed separately with FAST. Figure 5 shows the proportion of work time as a function of fatigue exposure for HFA,[10,11] signalmen, MOW workers, dispatchers, T&E crews, and passenger T&E crews. The fatigue exposure of accidents at the fatigue exposures  $\leq 70$  and  $\leq 90$  is well above that for any of the work groups. Conversely, the proportion of work time not fatigued ( $>90$ ) is the lowest for accidents. Clearly, high exposure to fatigue is a characteristic of HFA. T&E crews and dispatchers have a high exposure to fatigue.

Figure 6 shows the proportion of work time fatigued (FAST score  $\leq 90$ ) for each group and work schedule. The groups with the highest proportion of fatigued work time are dispatchers (with the exception of second shift) and T&E crews. Third shift dispatchers have the highest proportion of fatigued work time followed by variable start T&E crews, relief dispatchers, and extra board dispatchers. All of these jobs involve night work and/or circadian disruption. In contrast, T&E passenger jobs working split assignments and second shift dispatcher jobs have very little fatigue exposure. 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.[6] The correlations between FAST score, primary sleep, total sleep, and sleep periods for the 12 work schedule types on work days and rest days ( $N = 12 \times 2$ ) were also examined. FAST is reliably correlated with the duration of primary sleep ( $r = 0.657$ ,  $p < 0.000$ ) and total sleep ( $r = 0.586$ ,  $p < 0.001$ ), but not with number of sleep periods ( $r = 0.019$ ,  $p > 0.05$ ).

**Human factor accident probability and fatigue**

Workers involved in accidents have a high level of fatigue exposure. Fatigue exposure is a key determinant of accident probability and risk. Although fatigue exposure is known for accidents and for the five work groups shown in Figure 5, the frequency of HFAs as a function of FAST score is only known for accidents. Fatigue exposure is an important precursor to HFA and must be managed to prevent accidents.

The Poisson distribution [20] is often used to model rare, random events such as accidents. The Poisson distribution can be used to describe 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

$$p = e^{-\mu t} \left( \frac{\mu t^k}{k!} \right) \tag{1}$$

where  $\mu$  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  $p(\text{HFA}|\text{fatigue})$ , one needs to know the

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Table 3.  $\chi^2$  ( $df=4$ ) statistics comparing railroad employee group total workday daily sleep distributions with 2008 NSF *Sleep in America Poll* of US adults distribution.[9]

Group	Mean workday sleep (hours)	Proportion of workday sleep					N	$\chi^2$	p-value
		<6 (hours)	6 to <7 (hours)	7 to <8(hours)	8 to <9 (hours)	$\geq 9$ (hours)			
US adults	6.67	0.17	0.29	0.33	0.19	0.02	1000	–	–
Signalmen	6.82	0.12	0.49	0.33	0.06	0	388	72.67	$p < 0.0001$
MOW	6.75	0.13	0.50	0.33	0.02	0.01	252	65.65	$p < 0.0001$
Dispatchers	6.83	0.18	0.38	0.33	0.09	0.01	443	25.40	$p < 0.0001$
T&E	7.44	0.06	0.29	0.40	0.19	0.06	250	28.49	$p < 0.0001$
T&E passenger	7.17	0.10	0.30	0.41	0.15	0.04	240	12.13	$p < 0.05$

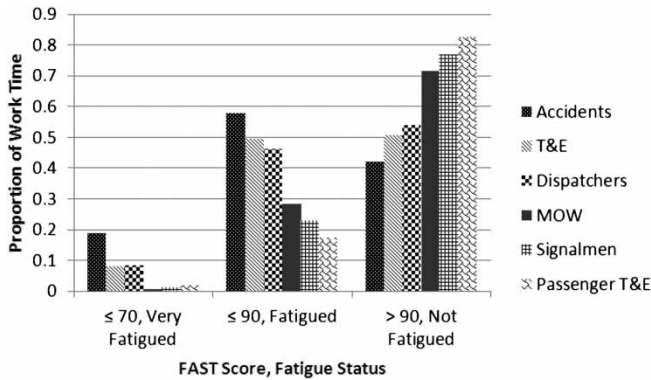


Figure 5. Fatigue exposure by work group and for accidents.

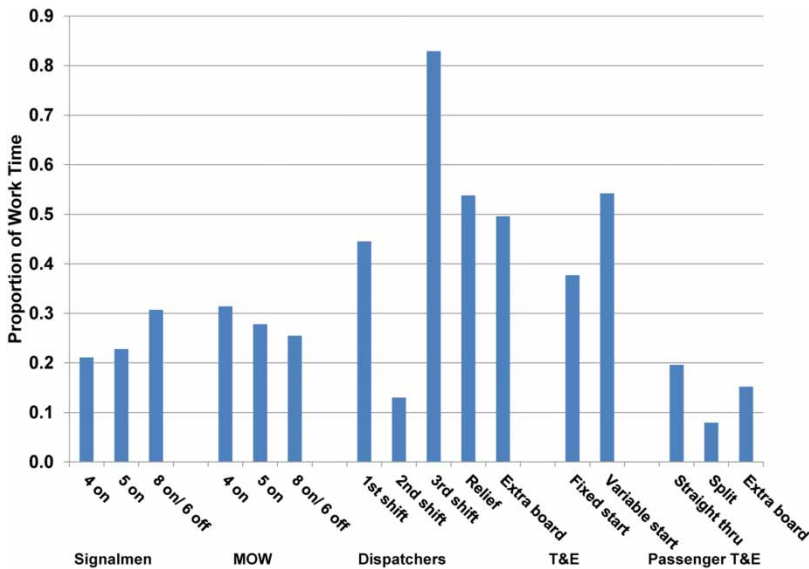


Figure 6. Percent fatigued ( $\leq 90$  effectiveness) by group and work schedule.

frequency of HFA at various levels of fatigue and the number of employee-hours (e-h) exposure at each level of fatigue.

The calculation of  $p(\text{HFA}|\text{fatigue})$  is detailed in Raslear et al. [21]. The number of HFA attributed to T&E crews (locomotive engineers and conductors) from January 2003 to June 2005 as a function of FAST score is shown in Table 4 (see [10,11], Table B-1). Table 4 also shows the estimated proportion of work time in each fatigue level based on 790 employees. Total employee hours (e-h) for the same railroads were obtained from the FRA database for the same time period, which indicated that 749,050,143 e-h were worked. 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  $\mu$  for Equation (1), from which the probability of one or more HFA per 200,000 e-h was obtained. Table 4 shows that, in the absence of fatigue (FAST > 90), the probability of one or more

Table 4. Calculation of HFA probability.

FAST score	≤50	>50–60	>60–70	>70–80	>80–90	>90
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
HFA per e-h ( $\mu$ )	$1.61 \times 10^{-6}$	$1.19 \times 10^{-6}$	$1.08 \times 10^{-6}$	$1.04 \times 10^{-6}$	$1.04 \times 10^{-6}$	$0.82 \times 10^{-6}$
Probability of $\geq 1$ HFA per 200,000 e-h	0.276	0.212	0.194	0.188	0.189	0.152

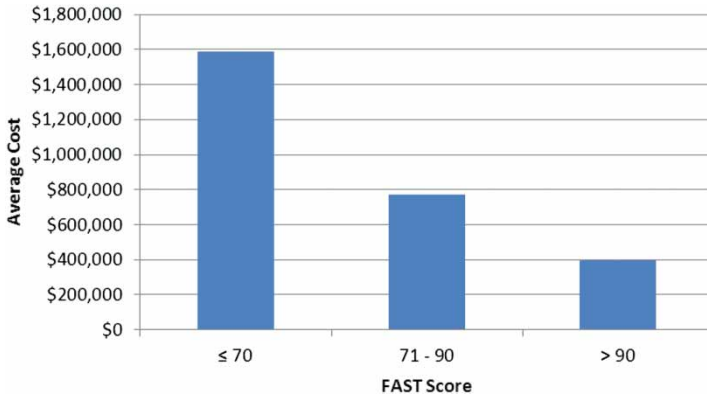


Figure 7. Average cost of a HFA as a function of FAST score.

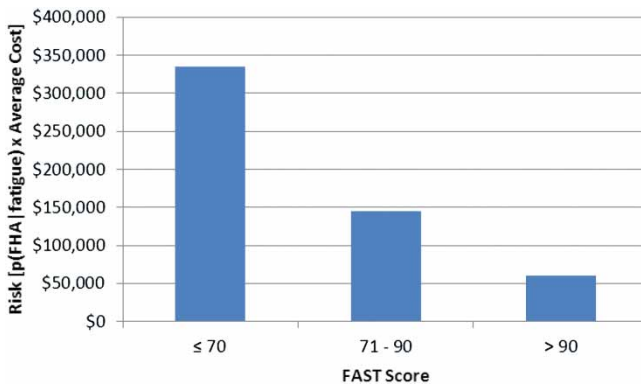


Figure 8. Risk of human factor accident as function of FAST score. Risk determined from probabilities in Table 4 and average costs in Figure 7.

HFA is 0.15. As fatigue increases, the probability of a HFA increases to 0.27. At a fatigue level  $\leq 70$ , the probability of a HFA is about 0.19. With exposure to fatigue, railroad accidents are 24–81% more likely than in the absence of fatigue.

**Human factor accident cost and risk**

In engineering, risk is defined as a collection of pairs of likelihoods and costs.[22] A common engineering definition of risk is the product of probability and cost. Risk in this view is the expected value of an accident.

Given  $p(\text{HFA}|\text{fatigue})$ , the calculation of risk only requires information about the cost of HFA for various effectiveness levels. Figure 7 shows the average cost of a HFA [12] for the same HFAs as shown in Table 4. Accidents involving fatigue have much higher associated costs than accidents where there is no fatigue ( $E > 90$ ). When the FAST score is between 71 and 90, average cost is double the cost with no fatigue ( $E > 90$ ). When the FAST score is  $\leq 70$ , the average cost is four times the cost with no fatigue. Figure 8 shows accident risk ( $p(\text{HFA}|\text{fatigue}) \times \text{cost}$ ) as a function of fatigue. Risk accelerates even more quickly than cost as a function of fatigue. When



the FAST score is between 71 and 90, risk is nearly 2.5 times the cost with no fatigue. When the FAST score is  $\leq 70$ , average cost is 5.1 times the cost with no fatigue.

## Discussion

Human factor accident probability increases with fatigue exposure. At FAST score  $< 70$ , it is increased by 28%. The cost of human factor accidents increases with fatigue exposure. At FAST score  $< 70$ , cost is increased by almost 200%. The risk (probability  $\times$  cost) of a human factor accident increases with fatigue exposure. At FAST score  $< 70$ , risk is increased by almost 500%.

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. [10,11] indicate that a critical fatigue exposure level occurs when the FAST score is  $\leq 70$  for 20% or more of work time. None of the five railroad occupations reaches this level as a group. However, one subgroup – third shift dispatchers – has 31.5% of work time with a FAST score  $\leq 70$ . Moreover, as Figure 6 shows, many other subgroups of employees have a fatigue exposure at FAST score  $\leq 90$  that exceeds or approximates that of workers who had accidents (58% of work time at FAST score  $\leq 90$ ). This includes first shift dispatchers (44.5%), third shift dispatchers (82.9%), relief dispatchers (53.8%), extra board dispatchers (49.6%), and variable start T&E crews (54.2%). This suggests that fatigue management for these subgroups could further reduce fatigue-caused HFA and be economically beneficial.

Since work schedules affect sleep patterns, and sleep patterns affect fatigue exposure, it seems natural to focus fatigue management on work schedules.[16] This report indicates that 34–43% of variance in fatigue exposure (FAST score) is due to sleep. Circadian rhythms account for 51% of the variance in fatigue exposure [11] and are difficult to change. However, 4–15% of the variance remains to be identified and should be used to manage fatigue. Education, diet, and the treatment of sleep disorders are among the factors that need to be considered for future quantification and fatigue management.

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 having a high fatigue exposure, T&E workers are also the group that works the most hours. Since the largest group of railroad employees is in the T&E crafts, the total number of hours at risk is substantial. This is a prime group for fatigue management.

The sleep pattern of railroad workers differs from that of US working adults. Railroad workers are more likely to get less than seven hours of total sleep on workdays, which potentially puts them at risk of fatigue, but railroad workers, on average, obtain more total sleep than US working adults. The fatigue exposure of US working adults, however, is not known because detailed records of work and sleep schedules do not exist that could be analyzed with a model such as FAST. Based solely on the available sleep information, it does not appear that railroad workers are more fatigued than US working adults.

In most work settings, including the railroad industry, the hours of work are accurately known because this is the basis of employee compensation. Information about sleep is usually not available unless special measures are taken to collect such data. In the present instance, work/sleep diaries were used to collect work and sleep information. As self-report data, there is always concern about reliability and accuracy,[23] and this is often cited as an issue in sleep research (e.g., [24]). However, it was noted previously that each of the surveys specified a level of reliability (95% confidence level) and error tolerance (15%) in determining the required sample size. Other studies have examined the agreement between the FAST AutoSleep estimates of sleep (AutoSleep is a module of FAST which estimates sleep from work schedules) and sleep from the five diary studies,[25] and between AutoSleep and actigraphy estimates of sleep.[26] The mean agreement between AutoSleep and the five diary studies was 87.17%. The agreement between AutoSleep and actigraphy was 86.92%. Since AutoSleep depends on input from the diary data, it appears that the required error tolerance or accuracy was approximated and it may be assumed that reliability was as well.

It is well known that sleep patterns change with age.[27] In the railroad industry it is also the case that jobs with less STV are often considered more desirable and are filled by employees with more seniority. Both of these factors have the potential to influence the data reported here. No attempt was made to stratify or otherwise adjust the data for these variables. Cost is one reason for not doing so. Stratification would require a different design with many more subjects. Moreover, the surveys were not intended to explore the influence of age and seniority on employee selection of work schedules. Rather, the objective of the surveys was to provide a first approximation to basic information about work schedules, sleep, and fatigue in the railroad industry. The results presented here certainly raise questions that can be explored in future research that builds on the groundwork this report provides.

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. A standard methodology yields benchmark data and affords the opportunity to assess the effects of future changes to work schedules as a result of new legislation and regulation. The use of a validated and calibrated fatigue model, such as FAST, allows quantification of fatigue exposure. Future work on fatigue in occupational groups should focus on similar methods to expand our knowledge of the role of work schedules on sleep, fatigue, and accident risk.

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