Journal of Safety Research 61 (2017) 53–64

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Time of day effects on railroad roadway worker injury risk

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ARTICLE INFO

Article history:
Received 15 December 2015
Received in revised form 7 November 2016
Accepted 20 February 2017
Available online 1 March 2017

Keywords:
Fatigue
Circadian
Roadway worker
Injury analysis
Human factors

ABSTRACT

Introduction: The purpose of this study is to examine how time of day affects injury risk of railroad maintenance of way employees and signalmen (roadway workers). Railroads reported 15,654 serious roadway worker injuries between 1997 and 2014. Roadway workers primarily work outdoors on or near railroad tracks and frequently encounter hazardous conditions. To avoid closing an active rail line during peak hours, railroads sometimes require roadway workers to work at night. Previous studies of roadway worker injury have not adequately accounted for exposure to time of day effects, nor have they investigated the human factors issues contributing to roadway worker injury. *Method:* The Federal Railroad Administration (FRA) database of injury reports provided data for circadian rhythm models of the odds of fatal and nonfatal injuries. The FRA database and fatal injury investigation reports also permitted an analysis of the circumstances and the human factors issues associated with injuries that occur at different times of day. *Results:* Odds of injury increased during nighttime work. The odds of nonfatal injury for both roadway worker crafts rose above 9:1 in the early morning hours. The relative odds of a fatal injury also increased significantly at night. A human factors analysis suggested that during all three shifts most nonfatal injuries involve workload, but workload was not identified as a factor in fatal injuries. *Conclusions:* Nighttime work is more hazardous for roadway workers than daytime work. Several factors related to fatigue and other conditions appear to increase the risk of injury during the outdoor, nighttime work required of roadway workers. *Practical application:* For practical reasons, nighttime roadway work is sometimes unavoidable. Therefore, new practices for nighttime work must be developed to adequately address fatigue and protect roadway workers from harm.

1. Introduction

Risk of injury is associated with railroad work under a variety of circumstances. Maintenance of way (MOW) employees and signalmen are roadway workers who work outside on or near active tracks for substantial periods of time. MOW employees are responsible for building and maintaining railroad tracks and structures, while signalmen are responsible for building and maintaining signaling, switching, and communication equipment along the railroad. The most obvious hazard for roadway workers is being struck by a moving train. The primary forms of protection against moving trains for MOW employees and signalmen are posting a watchman to provide track warning; foul time, which keeps trains from operating in a work zone for a limited period of time; taking a track out of service; and individual train detection, which requires a lone worker to visually detect a train's approach and move to safety at least 15 s before the train's arrival at the worker's location. These protections are necessary because a freight train traveling at full speed has enough momentum that it may be impossible to stop the train in time to avoid an accident, even if the engineer sees a worker on the tracks.

While working on or alongside active train tracks may be the most salient hazard of railway work, it is not the only one. Railway work also often involves operating heavy machinery, working on surfaces with unstable footing, and working under adverse weather conditions. During a routine daytime shift, job tasks frequently involve exposure to these and other potential hazards; a seemingly minor error can lead to injury or death. Maintenance of way and signal maintenance can occur at all hours, and hazards that can be avoided during the daytime may be harder to see and avoid during nighttime work. Constant vigilance, adherence to safety protocols, and effective communication among work gang members are among the procedures and precautions that are necessary to prevent an accident. When serious accidents and incidents do occur, railroads must report them to the Federal Railroad Administration (FRA). Human factors are reportedly the most frequent cause of accidents among roadway workers. In an analysis of the FRA Accident/Incident Report Database, Guthy, Rosenhand, Bisch, and Nadler (2014) found that railroads attribute 48.1% and 54% of all

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http://dx.doi.org/10.1016/j.jsr.2017.02.007
0022-4375/Published by Elsevier Ltd. on behalf of National Safety Council.

casualties among MOW employees and signalmen, respectively, to human factors.[1]

Previous efforts to improve railway worker safety have focused on minimizing fatigue as a cause of error, because both signalmen and MOW employees respond to emergencies at night, and the late night is associated with a peak in operator error during the circadian low from approximately 02:00–05:59 (e.g., Gander et al., 2011; Horne & Reyner, 1995; Pruchnicki, Wu, & Belenky, 2011). The circadian time system, marked by a regular pattern of body temperature fluctuations that correlate with time of day, is frequently conjoined with the duration of time since waking, both of which contribute to fatigue effects on operator performance (Carrier & Monk, 2000). Gertler, DiFiori, and Raslear (2013) found that the amount of sleep, and the time of day when sleep occurs, account for 85% to 96% of fatigue exposure of train and engine workers, signalmen, maintenance of way workers, and dispatchers.

Hours of service regulations, intended to promote safety (Sussman & Coplen, 2000), apply to signalmen and require a specified number of hours off duty (Hours of Service of Railroad Employees, 2011). There is not an equivalent hours of service regulation for MOW employees. Hours of service regulations can constrain hazards associated with fatigue originating from continuous work duration (see Miller, 1976), but do not alleviate circadian effects (Gander et al., 2011) or prevent fatigue (Thomas, Raslear, & Kuehn, 1997). Beyond fatigue and circadian rhythms, nighttime work may be more dangerous for railway workers than daytime work because low light conditions reduce sight distances and make it harder to see environmental hazards (e.g., poor footing conditions). These considerations all predict an elevated risk of injury during nighttime work among MOW employees and signalmen.

The FRA Accident/Incident Report database documents the circumstances of each injury reported by railroads to the FRA. We analyzed this database to determine whether railroads report more injuries at night compared to the day than would be anticipated from the proportion of employees on duty at night and during the day (i.e., exposure to risk). This analysis consisted of the calculation of odds ratios as a measure of relative risk. We also determined whether daytime and nighttime injuries occur under the same circumstances.

2. Previous research

Research on occupational risk by time of day across a range of transportation domains and industries supports the hypothesis that nighttime work is more dangerous than daytime work. A review by Williamson and colleagues found a greater risk of accident at night in a variety of transportation modes, from automobile to aviation (2011). Horne and Reyner (1995) and Langlois, Smolensky, Hsi, and Weir (1985) found a higher risk of single-driver accidents for both cars and trucks during the night. Similarly, an elevated risk for nighttime work has been found in the manufacturing sector (Smith, Colligan, & Tasto, 1982; Smith, Folkard, & Poole, 1994). Workers on a night shift encounter the highest risk of accident around midnight, with an additional period of increased risk around 03:00 (Folkard, 1997; Folkard, Lombardi, & Spencer, 2006).

A higher rate of human error due to fatigue has been found in controlled experimental studies. Fatigue can reduce performance in a variety of ways that could result in injuries. It has been found to produce slower reaction times and lapses in a psychomotor vigilance task and an increase in lane drift during a simulated driving task (Baulk, Biggs, Reid, van den Heuvel, & Dawson, 2008). Fatigue has also been linked to reduced performance on divided attention tasks (Drummond & Brown, 2001). Sauer, Wastell, Hockey, and Earle (2003) found that nighttime performance in a complex process control task environment was associated with the deliberate use of corner cutting strategies focused on maintaining primary task performance at the expense of secondary task elements.

Although no studies have examined the effects of nighttime work on reaction time, vigilance, divided attention, and multi-tasking strategies of MOW employees and signalmen, research has investigated the prevalence and effects of fatigue in railroad employees. Fatigue, as assessed with the biomathematical Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) model (Raslear, Hursh, & Van Dongen, 2011) predicts the probability of railroad accidents among on-call railroad engineers (Hursh, Raslear, Kaye, & Fanzone, 2008) and employees in other railroad crafts (Raslear, Gertler, & DiFiore, 2013). The SAFETE model provides input to the Fatigue Avoidance Scheduling Tool (FAST). Using this tool, Gertler et al. (2013) found that as a group, MOW employees and signalmen in the United States worked for nearly a thousand hours while very fatigued during the study year.

Some forms of protection for roadway workers who are working on or near active railroad tracks are entirely dependent upon vigilance. Fatigue could reduce the cognitive performance of MOW employees and signalmen increasing the likelihood of an accident resulting in a serious injury or fatality. Under circumstances where more than one worker is working on an active track, a watchman may be designated to warn other employees of an approaching train. Under circumstances where a roadway worker is working alone, the lone worker may be responsible for providing his or her own on-track safety. Reduced vigilance could cause either of these forms of protection to fail and increased reaction time would provide less time to move clear of the tracks after a train is detected. Impairment in divided attention could decrease the ability of a roadway worker to detect an approaching train, especially if attention is focused on the work at hand.

The primary objective of this study is to determine whether nighttime work is associated with higher odds or risk of serious injuries among MOW employees and signalmen than daytime work. We analyzed the distributions of injuries across times of day coupled with exposure rates to determine the effect of time of day on the odds of injury. We determined the times of day when MOW employees and signalmen experienced heightened odds of injury attributed to human factors.

The second objective is to analyze both fatal and nonfatal injuries. Investigations of roadway worker accidents that focus only on fatalities would limit the sample size that is available for analysis, which reduces the power of statistical tests and would create difficulty in generalizing from any temporal patterns that emerge. Accidents among MOW employees and signalmen that result in nonfatal injuries are several orders of magnitude more frequent than those that result in fatal injuries. By considering accidents resulting in both fatal and nonfatal injuries, we dramatically improve our ability to draw inferences from meaningful patterns.

The third objective of this study is to explore whether injuries among MOW employees and signalmen are associated with the same human factors causes, and whether they occur under the same circumstances at all times of day. Findings may suggest different approaches to improving safety for daytime and nighttime work.

3. Method

To compare daytime and nighttime accident risk, we examined all MOW employee and signalman injuries attributed to human factors that railroads reported to the FRA from January 2, 1997 to February 27, 2014. The year 1997 was selected as the start because this is when the Roadway Worker Protection Rule went into effect. Prior to 1997, roadway workers worked under a different set of safety regulations, so data prior to 1997 may not be directly comparable to those that are more recent. Data on MOW employee and signalmen injuries are

[1] The FRA Office of Safety makes available railroad safety data that railroads update monthly. See http://safetydata.fra.dot.gov/OfficeofSafety/default.aspx. Employee injury criteria that require reporting include medical treatment beyond first aid, one or more days away from work, or loss of consciousness. Attribution to human factors indicates that the railroad believes that the railroad employee may have been at least partly responsible for causing the accident/incident.

available in the FRA Accident/Incident Report Database including the time of the accident, whether or not the injury was fatal, and the circumstances of the accident. We used work schedule data from Gertler and Viale (2006a, 2006b) to determine the exposure of roadway workers to potentially hazardous conditions at each time of day. Finally, we reviewed detailed FRA Fatality Investigation Reports to obtain additional information about the causes of fatal injuries that occurred over the same time period. The final analytic dataset included 15,654 records after applying all selection criteria: 15,595 nonfatal injuries and 59 fatalities. Each of these data sources is discussed in more detail below.

3.1. FRA Accident/Incident Report Database

The Accident/Incident Report Database, specifically the Railroad Injury and Illness Summary,[2] was used to determine how injuries involving railway employees were distributed across time of day. This database contained details of the 185,768 injuries reported for all railroad crafts. We limited our selection to cases in which the person injured was an MOW employee or a signalman and the probable reason for injury was specifically identified as "human factors," or another probable reason that we considered to be in the domain of human factors, including "procedures for operating/using equipment not followed," "lack of communication," "insufficient training," or "impairment, physical condition, e.g. fatigue." The initial analytic dataset included records of 15,595 nonfatal injuries and 120 fatal injuries that fit the purposes of the current study, before any additional selection criteria were applied.

Each accident/incident record is associated with one circumstance code in each of six categories (FRA, 2011, Appendix F): Physical Act (what the person was doing when hurt, e.g., lifting equipment or walking); Location Part I (whether the accident occurred on or near a railroad right of way, or if not, at what site it did occur, e.g., on the main/branch track or in the repair shop); Location Part II (the kind of on-track equipment or vehicle that was involved, if any, e.g., a moving freight car or an automobile); Location Part III (the location of the injured person, e.g., whether the person was on/in/under a locomotive or rail car or on/beside/between tracks); Event (what kind of accident occurred, e.g., struck by on-track equipment or slipped, fell or stumbled); and Tools, Machinery, Appliance, Structures, Surface, Etc. (e.g., power tools or a pry bar). These six categories include approximately 380 circumstance codes.

3.2. Exposure to roadway work

To obtain measures of exposure to working conditions for MOW employees and signalmen, Gertler and Viale obtained the work schedules of 254 MOW employees (2006a) and 389 signalmen (2006b) from daily activity logs recorded over two weeks. Employees from each craft were randomly selected from employee union databases. FRA made these data publically available in 2008.[3]

3.3. FRA fatality investigation reports

FRA Fatality Investigation Reports were a third source of data. These reports contain a description of how the accident occurred (including the actions of all personnel in the vicinity during the time leading up to the fatality), an analysis, conclusions, and in most cases a brief description of the probable cause and contributing factors. FRA inspectors typically conduct a fatigue analysis, list applicable railroad rules and federal regulations and whether they were followed, and whether the employee was current on mandatory training. These reports also typically contain extensive supporting documentation.

The 120 fatalities identified in the Accident/Incident Report database that involved MOW employees or signalmen were subject to additional selection criteria based on availability and content of the Fatality Investigation Reports for the corresponding incidents. The authors analyzed the content of 106 reports; 14 reports could not be located. Two of the authors coded each report's textual narrative and a third author mediated disagreements and served as a tiebreaker when necessary.

Coding indicated whether or not the report's text signified that one or more human factors cause codes applied to the accident.[4] We omitted the categories of human–machine interface, physiological, and troubleshooting since they were deemed not applicable to the context of roadway work; we added the category of not following procedures. Thus, our modified list of categories of human factors cause codes included communication breakdown, confusion, distraction, fatigue, following procedures, situational awareness, time pressure, training/qualification, and workload.

Of the 106 fatality reports analyzed for content, 47 were omitted because the cause of death was not human factors (usually either illness or a traffic accident that occurred outside of the railroad right of way). Thus, the final sample size of fatalities consisted of 59 fatalities (45 MOW employees, 14 signalmen) that could be confirmed as having a human factors cause.

3.4. Analysis

Odds ratios were calculated to determine the association between roadway worker injury during work and time of day work was done. Counts of injuries and fatalities among each craft were used to calculate the odds of injury at each time of day. The Gertler and Viale data were used to calculate the odds each craft was on shift at each time of day. Odds ratio was chosen as a metric because the design of the current study approximates a case–control design, and because injuries are relatively rare events (Kestenbaum, 2009). No data were available on work schedules for the workers injured; instead, work schedules were collected from a second sample of uninjured workers, acting as a pseudo-control group. The odds ratio is expressed relative to exposure so that an odds ratio of 1.0 for a given time of day indicates no association between injury and this time of day, an odds ratio greater than 1.0 indicates higher odds of injury occurring at this time of day, and an odds ratio less than 1.0 indicates lower odds of injury occurring at this time of day, compared to other times of day.

The injury analyses compared the two crafts. The dataset drawn from the Accident/Incident Report database included a sufficient number of nonfatal injuries occurring at each of the 24 h of the day for both MOW employees and signalmen to calculate the odds of injury during each hour of the day. However, due to the much smaller number of fatalities, there were times of day with no fatalities for either craft. Therefore, the fatality data were aggregated across crafts and across times of day collapsing the numbers of injuries that occurred during each of the 24 h of the day into 6 bins, each representing a 4-h period of time. This was done to eliminate the times of day when zero fatalities occurred and odds ratios could not be calculated.

In order to aggregate exposure across crafts, it was necessary to create an exposure measure representative of exposure among the combined populations of MOW employees and signalmen. The samples of MOW employees and signalmen surveyed by Gertler and Viale to estimate work schedules were approximately equal. However, the population of MOW employees in the United States is substantially larger than signalmen. A weighted average was calculated based on the proportion of roadway workers working at each time of day in each craft during each year from 1997 to 2014, based on membership in the craft union

[2] These casualty data are available at http://safetydata.fra.dot.gov/OfficeofSafety/publicsite/on_the_fly_download.aspx.

[3] The time of day datasets that were obtained in these studies are: *Railroad Maintenance of Way Employee Background Survey* (http://www.fra.dot.gov/eLib/details/L04108) and *Railroad Signalmen Background Survey* (http://www.fra.dot.gov/eLib/details/L04111).

[4] Cause codes are based on the NASA Aviation Safety Reporting System. See http://asrs.arc.nasa.gov/docs/dbol/ASRS_CodingTaxonomy.pdf.

as shown on the U.S. Department of Labor Office of Labor-Management Standards website.[5]

Odds ratios were calculated with Eq. (1), dividing the odds of injury at a time of day by the odds of a worker in a given craft working at that time of day. The odds of injuries at a time of day was obtained by dividing the number of accidents at that time (A) by the number of accidents at all other times of day (B). The odds of an employee working hours at a time of day was obtained by dividing the number of worker hours in that bin (C) by the total number of worker hours at all other times of day (D). However, since injuries at certain times of the day are rare, calculating standard errors on the odds ratio directly can lead to confidence intervals that include negative values. To avoid this issue, we constructed confidence intervals around the natural logarithm of the odds ratio. Eq. (2) was used to approximate the standard error of the natural logarithm of the odds ratio. For interpretability, we then use Eq. (3) to transform the corresponding confidence intervals into the implied bounds for the odds ratio (Ahlbom, 1993, p. 76).

$$OR = \frac{{}^{A}/_{B}}{{}^{C}/_{D}} \tag{1}$$

$$SE\{ln(OR)\} = \sqrt{{}^{1}/_{A} + {}^{1}/_{B} + {}^{1}/_{C} + {}^{1}/_{D}} \tag{2}$$

$$CI_{95\%}(OR) = \left(e^{ln(OR)-1.96*SE\{ln(OR)\}}, e^{ln(OR)+1.96*SE\{ln(OR)\}}\right). \tag{3}$$

Following the calculation of odds ratios at each time of day, optimized models were created to fit each set of estimates. These were intended to represent circadian variation in odds of injury. This equation takes the form of a function composed of the sum of two cosine waves, one with a period of 24 h and the other with a period of 12 h. The form of the circadian model used is based on Hursh et al. (2004) and is reproduced in modified form here in Eq. (4), where T is the time of day in hours, p is the peak of the 24 h rhythm, p′ is the relative time of the 12 h peak, α is the amplitude of the 24 h peak, β is the amplitude of the 12 h peak, and γ is the offset of the 24 h rhythm.

$$OR_T = \alpha\ \cos(2\pi((T-p)/24+\gamma)+\beta cos(4\pi(T-p-p')/24). \tag{4}$$

Model parameters were optimized through nonlinear least squares regression.

As discussed in the previous section, the Accident/Incident Report database contains a number of categorical variables that describe the circumstances surrounding each reported injury. Each of these circumstance variables, Physical Act, Location A, Location B, Location C, Event, and Tools includes a lengthy list of specific circumstance variables. We focused on identifying a short list of the specific circumstances that were associated with greater odds of injury during nighttime work.

Any circumstances of fewer than 100 injuries were dropped from the analysis. Odds ratios and their confidence intervals were calculated for each remaining circumstance for each hour of the day and for each craft. We then tested whether the odds of injury in a particular circumstance were different from the overall odds of injury by determining whether the point estimate of overall odds fell within its confidence interval. Given the large number of circumstance variables analyzed, we used a 99% confidence to reduce Type I error. In the following section we report circumstances that were significantly different during nighttime work from the overall odds of injury.

4. Results

Injury data spanned 18 years of work among roadway workers. Given this lengthy span of time, it is possible that other qualitative changes occurred that would influence injury rates across times of day. To examine the possibility that unknown time-varying factors may have resulted in changes to injury rates, we compared the hourly distribution of injuries from 1997 to 2005 to those from 2006 to 2014. A chi-square test of independence found a significant association between these two distributions, χ^2 (23, N = 15,595) = 44.20, $p < .01$. Post hoc Z-tests revealed significant differences at 3 hours of the day: 05:00, 10:00, and 18:00 ($p < .05$) in the proportion of injuries occurring across years. Therefore, in the subsequent primary analyses, separate analyses were conducted for injuries from 1997 to 2005 and for injuries from 2006 to 2014. A similar chi-square test was conducted for fatality rates, but did not identify a significant association between years and time of day for fatalities (χ^2 (15, N = 59) = 13.03, $p > .05$).

The numbers of injuries and fatalities that occurred at each time of day are shown in Table 1. While the number of injuries varies substantially between years and crafts, the percentage of injuries occurring at each time of day is quite similar, as shown in Fig. 1. The total number of fatal injuries is much lower, but the percentage of fatal injuries at each time of day exhibits a similar distribution, as shown in Fig. 2. The proportion of employees working at each time of day is shown in Fig. 3a, and Fig. 3b shows the subset for night in greater detail. The x-axes indicate the hour at which the interval begins.

4.1. Odds of injury by time of day

Odds ratios of nonfatal injury by time of day and their confidence intervals for each set of years and each craft are shown in Figs. 4 and 5, from 1997 to 2005 and from 2006 to 2014, respectively. Odds ratios for fatal injuries are summarized in Fig. 6. Forty-three fatalities occurred during the first shift, 10 during the second shift, and 6 during the third shift. The circadian model provided a good fit for the odds ratio estimates for models of MOW nonfatal injuries from 1997 to 2005 (R^2 = 0.73) and from 2006 to 2014 (R^2 = 0.77), signalmen nonfatal injuries from 1997 to 2005 (R^2 = 0.85) and from 2006 to 2014 (R^2 = 0.77), and fatal injuries (R^2 = 0.95). Model predictions are included in Figs. 4–6, with the optimized parameters for Eq. (4) for each model included below each figure.

Table 1
Count of injuries and fatalities at each hour of the day.

Time of day	Injuries				Fatalities
	MOW		Signalmen		
	1997–2005	2006–2014	1997–2005	2006–2014	
0:00	53	43	30	18	0
1:00	79	66	31	30	0
2:00	85	64	33	23	1
3:00	61	57	28	29	0
4:00	55	43	18	29	0
5:00	53	60	12	13	2
6:00	103	104	33	15	2
7:00	300	212	67	44	1
8:00	591	440	139	71	4
9:00	779	559	172	125	6
10:00	1047	718	237	153	7
11:00	903	674	214	148	7
12:00	535	433	126	98	6
13:00	729	517	149	107	10
14:00	727	500	168	104	1
15:00	412	344	109	54	2
16:00	244	184	57	47	4
17:00	138	120	49	18	0
18:00	64	78	30	26	3
19:00	64	39	15	21	0
20:00	28	38	24	17	1
21:00	36	34	11	13	1
22:00	40	34	15	9	1
23:00	41	39	23	26	0
Total	7167	5400	1790	1238	59

[5] See www.dol.gov/olms/.

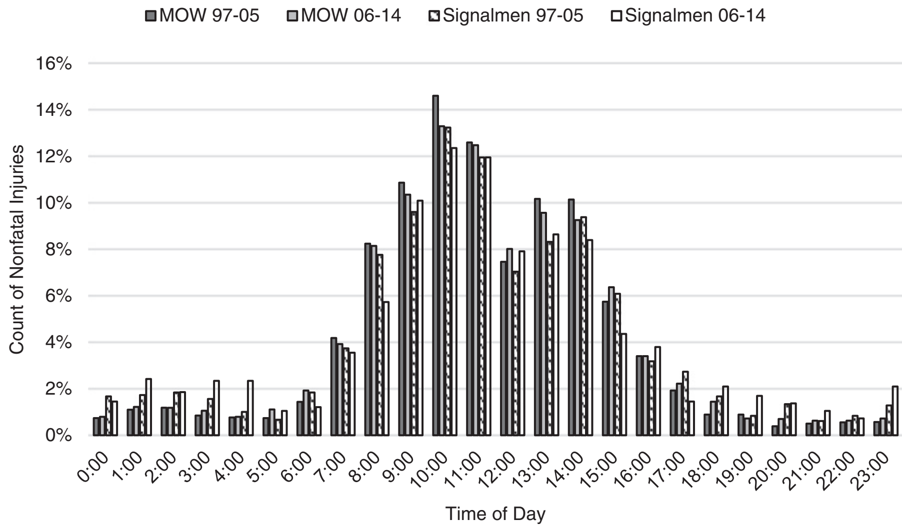

Fig. 1. Percentage of nonfatal injuries at each hour of day.

The highest odds of a nonfatal injury occurred early in the morning for both crafts. For MOW employees, across both sets of years, the odds were highest between 02:00 and 02:59. For signalmen, from 1997 to 2005 the odds were highest from 2:00 to 2:59, while from 2006 to 2014 the odds were highest slightly earlier in the night, from 01:00 to 01:59. The times between 23:00 and 04:59 were associated with relatively high odds of nonfatal injury. For fatal injuries among both crafts, only the period of time from 20:00 to 23:59 was associated with odds of injury significantly higher than 1.00. The ratio that compares fatal injury odds during those hours to the overall odds of a fatal injury was 6.5:1 based on three fatalities that occurred during a period with relatively few employees working.

4.2. Circumstances of nonfatal injuries that occur at night

A secondary analysis was conducted to identify the circumstances that resulted in higher odds of nonfatal injury at night. The primary analysis consistently identified nighttime as associated with the highest odds of nonfatal injury, in both 1997 to 2005 and 2006 to 2014 subsets of data; therefore, this subdivision of the data was not maintained for secondary analyses. After applying the filtering criteria described in Section 3.4, and omitting circumstances that were only significantly different from the overall odds of injury during the first shift (08:00 to 15:59), when the overall odds of injury were near 1.0, we obtained sets of 12 circumstances for each craft that applied to nonfatal injuries among MOW employees (Fig. 7) and signalmen (Fig. 8) during their second and third shifts. All of the data points illustrated in Figs. 7 and 8 are significantly different from the overall odds shown as a solid black line.

For MOW employees, the circumstances representing higher odds of nonfatal injury than the overall odds during the second and third shifts are Physical Act (walking, sitting); Location Part I (passenger terminal, repair, repair shop); Location Part III (at work station, in rail car, on stairs); Event (collision/impact, slipped); and Tools, Machinery, Appliance, Structures, Surface, Etc. (floor, non-rail motor vehicle). For signalmen, these circumstances are Physical Act (driving, lifting equipment, stepping down, walking); Location Part III (on tracks, at work station); Event (struck against object, slipped); and Tools, Machinery, Appliance, Structures, Surface, Etc. (ballast, cable, non-rail motor vehicle). Walking and non-rail motor vehicles and slipping, tripping or falling were associated with higher odds of nonfatal injury at night among both crafts, although the condition that resulted in slipping differed.

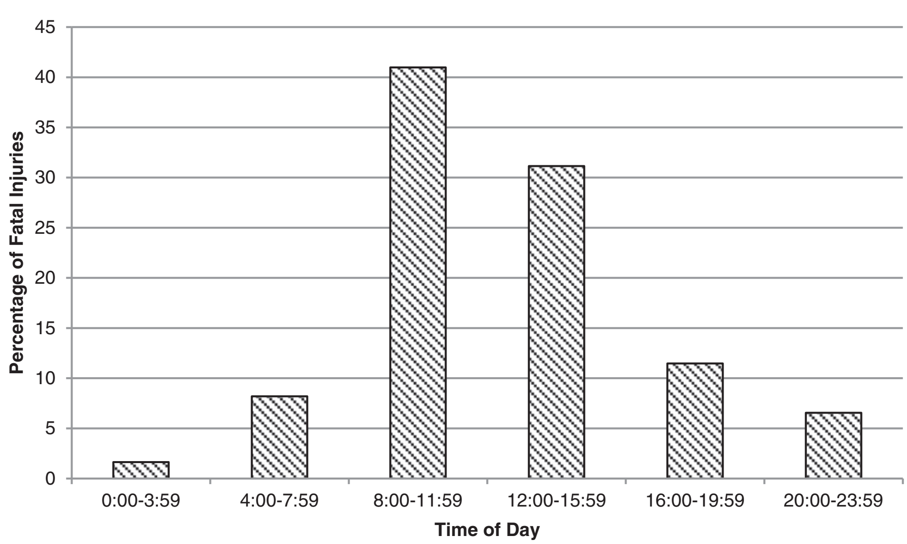

Fig. 2. Percentage of fatal injuries by time of day interval for both MOW employees and signalmen.

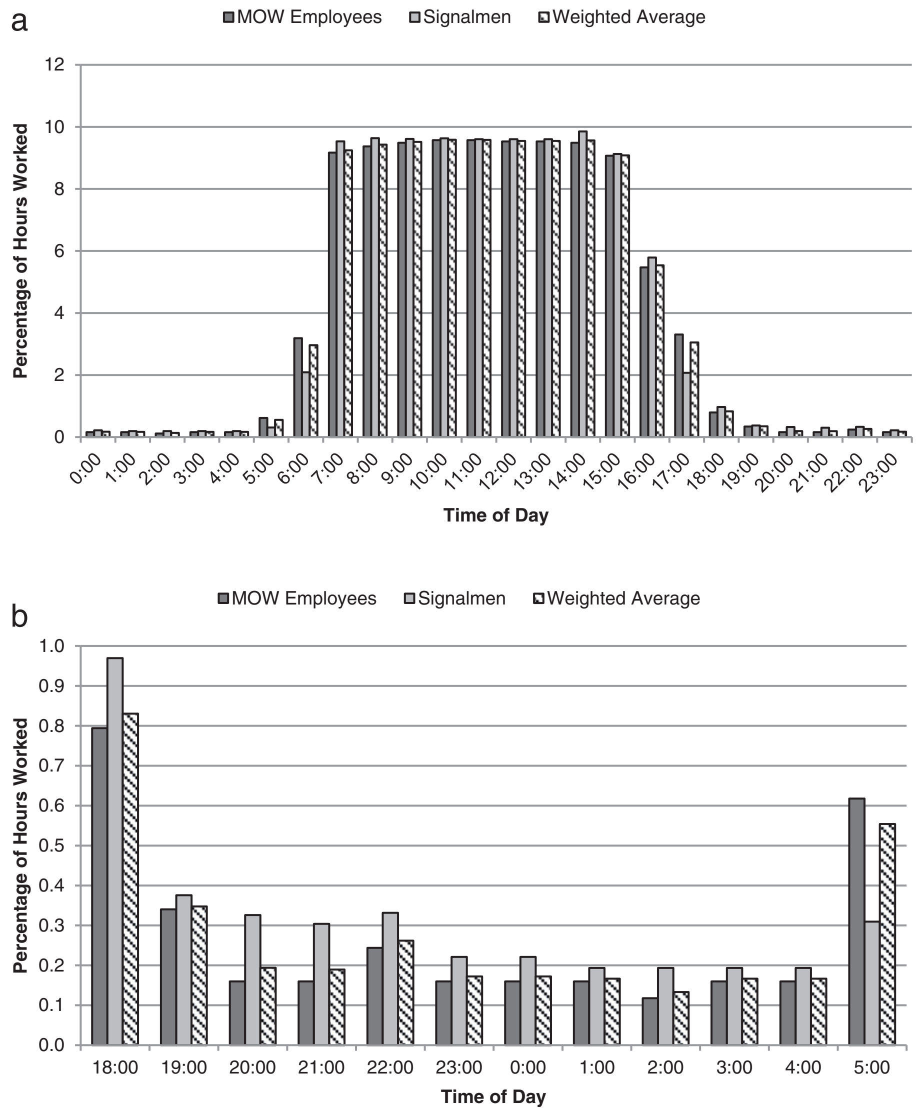

Fig. 3. a. Percentage of MOW employees and signalmen working at each time of day. b. Percentage of MOW employees and signalmen working from 18:00 to 05:59 (detail).

4.3. Analysis of human factors fatalities at night

The human factors cause codes assigned to the 59 fatality reports are summarized in Figs. 9 and 10. Of these, 54 (92%) provided sufficient information for the assignment of at least one human factors cause code. Workload did not apply to any fatality report. On average, each fatality report was assigned 2.4 codes. Lack of situational awareness, miscommunication, and failure to follow procedures were the most frequent human factors issues identified in these reports; each was identified in at least half of the fatality reports, and all three causes occurred together in 11 of the 59 fatalities. Training and qualification issues contributed to all signalman fatalities reviewed. Miscommunication, and training and qualification appear to be more common among MOW employee fatalities that occurred during the third shift. Following procedures appears more common among signalman fatalities that occurred during the second and third shifts.

4.4. Analysis of nonfatal human factors injuries at night

The final analytic dataset contained 15,595 nonfatal injury records of which 6102 included a narrative description. Of those with a narrative 5091 concerned MOW workers and 1011 concerned signalmen. Narratives were searched for a list of keywords indicating each human factors cause code. Of these reports 864 (14%) were assigned at least one human factors cause code. Substantially fewer human factors cause codes were assigned to nonfatal injuries than fatal injuries because the database narratives describing the nonfatal injuries have much less information than the more detailed fatality investigation reports. As a result, on average, narratives were assigned 0.15 codes. Figs. 11 and 12 illustrate the distribution of human factors causes applied to the narrative entries for MOW employees and signalmen, respectively. Workload was by far the most commonly represented human factors cause in the narrative entries for both crafts. Situational awareness, time pressure, and failure to follow procedures were all also commonly identified. Similar percentages of codes were assigned to narratives of injuries that occurred during each of the three shifts.

5. Discussion and conclusion

Our results indicate that for both maintenance of way (MOW) employees and signalmen, work that occurs at night or early in the morning (18:00 to 05:59) is associated with higher odds of both fatal and nonfatal injuries. Furthermore, a large portion of the variation in odds of injury across times of day can be explained by a circadian rhythm model. The highest relative odds of nonfatal injury were found at

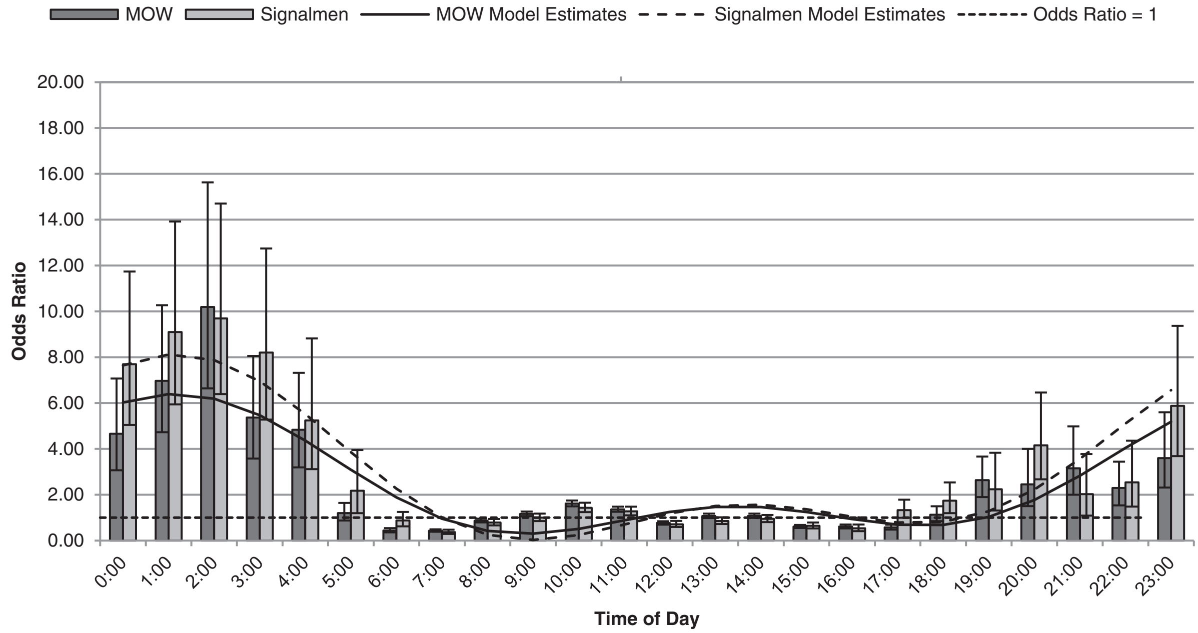

Fig. 4. Odds ratios for nonfatal MOW employee and signalman injuries, 1997–2005. Note: The equation for the illustrated MOW fit line for injuries: $OR_T = 2.46\cos(2\pi((T+23.06)/24+2.46)+1.48\cos(4\pi(T+23.06-36.30)/24)$. The equation for the illustrated signalmen fit line for injuries: $OR_T = 3.31\cos(2\pi((T-96.84)/24+2.98)-1.86\cos(4\pi(T-96.84-54.47)/24)$.

02:00 to 03:00 for both MOW employees and signalmen (01:00 to 02:00 for signalmen from 2006 to 2014), consistent with an effect of the circadian low phase. These odds rose above 9:1, similar to the peak increase in odds of road accidents at night (Williamson et al., 2011). The combined MOW employee and signalmen fatality data showed significantly heightened odds for fatal injuries between 20:00 and 23:59, prior to the circadian low phase, although this finding is based on only three fatalities that occurred during this period. Although the patterns of nonfatal injuries are consistent with what would be expected from the contribution of circadian effects, the paucity of data requires caution prior to drawing any conclusion about possible circadian effects on fatal injuries. The analysis of fatal injury reports and database narratives suggests that fatal and nonfatal human factors contributions also differed. Nonfatal injuries were attributed primarily to workload at all times of day. In contrast, no evidence was found identifying workload as a contributing factor in any of the fatal injuries analyzed. Factors contributing to fatal injury differed by craft and by time of day. The analysis of fatality reports revealed the predominance of three categories of human factors: miscommunication, following procedures, and situational awareness, which together represented 76% of the human factors codes assigned by the researchers to the fatality reports.

Possible explanations for the high odds of nonfatal injury during early morning hours include the effects of time on task, circadian low phase, hours of continuous sleep in the previous 24 h, and the

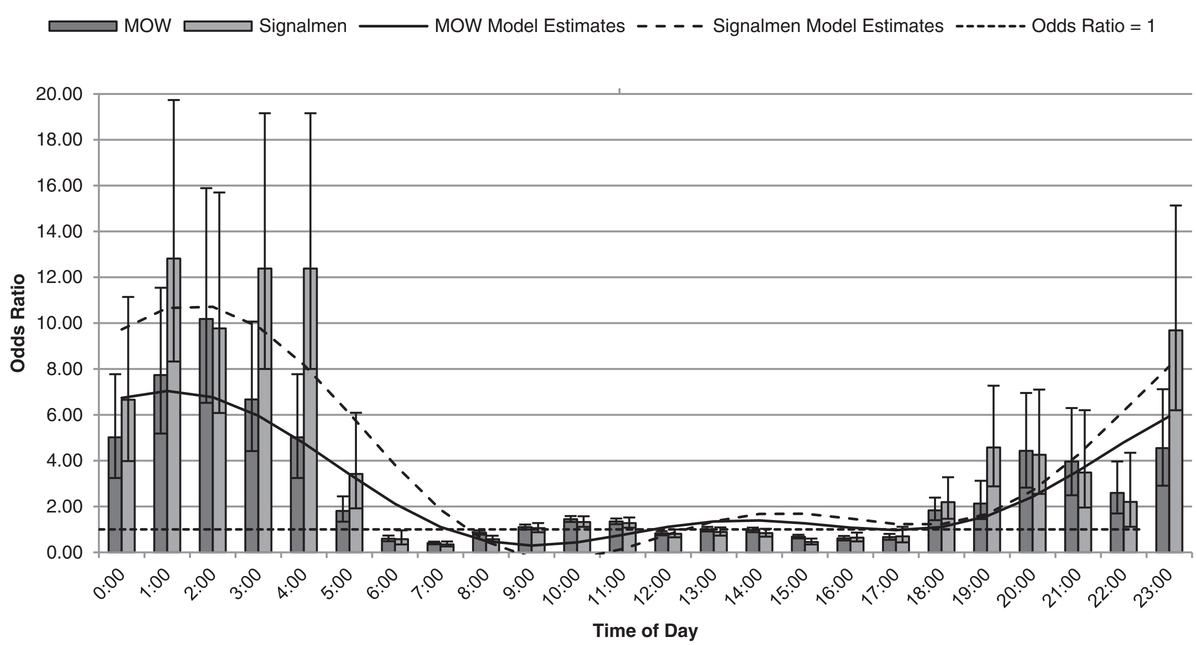

Fig. 5. Odds ratios for nonfatal MOW employee and signalman injuries, 2006–2014. Note: The equation for the illustrated MOW fit line for injuries: $OR_T = 2.86\cos(2\pi((T+23.32)/24+2.77)+1.43\cos(4\pi(T+23.32-36.52)/24)$. The equation for the illustrated Signalmen fit line for injuries: $OR_T = 4.65\cos(2\pi((T-97.08)/24+3.89)-2.32\cos(4\pi(T-97.08-54.72)/24)$.

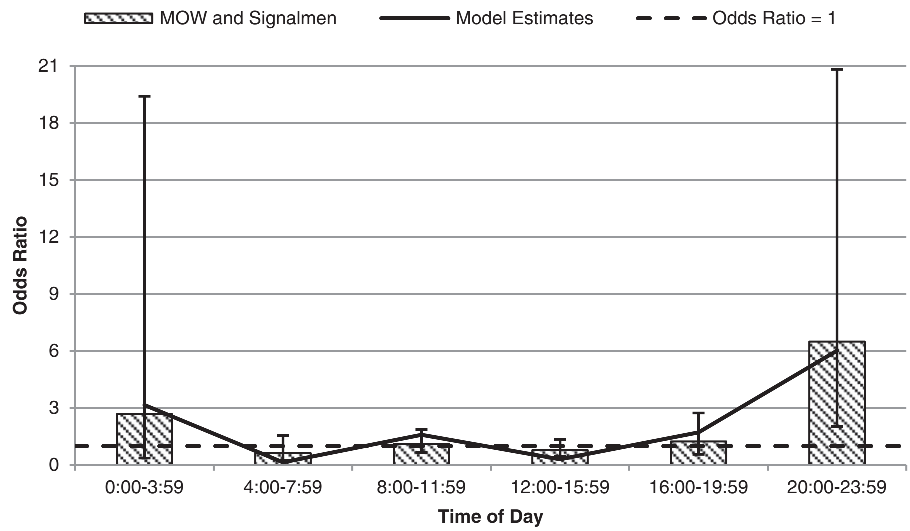

Fig. 6. Odds ratios for fatal MOW employee and signalman injuries. The equation for the illustrated fit line: $OR_T = 2.24\cos(2\pi((T-310.63)/24+2.16)) - 1.71\cos(4\pi(T-310.63-281.89)/24)$.

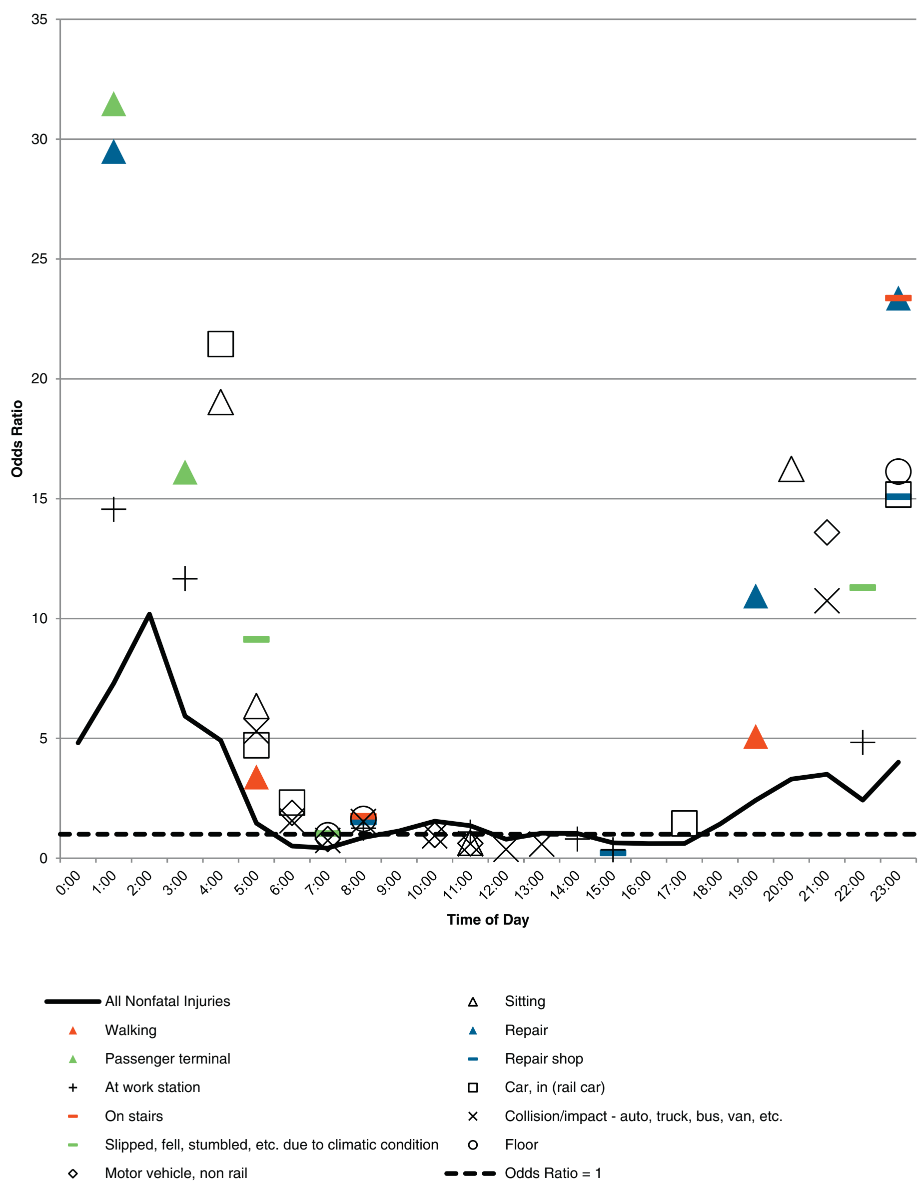

Fig. 7. Circumstances of nonfatal injury among MOW employees.

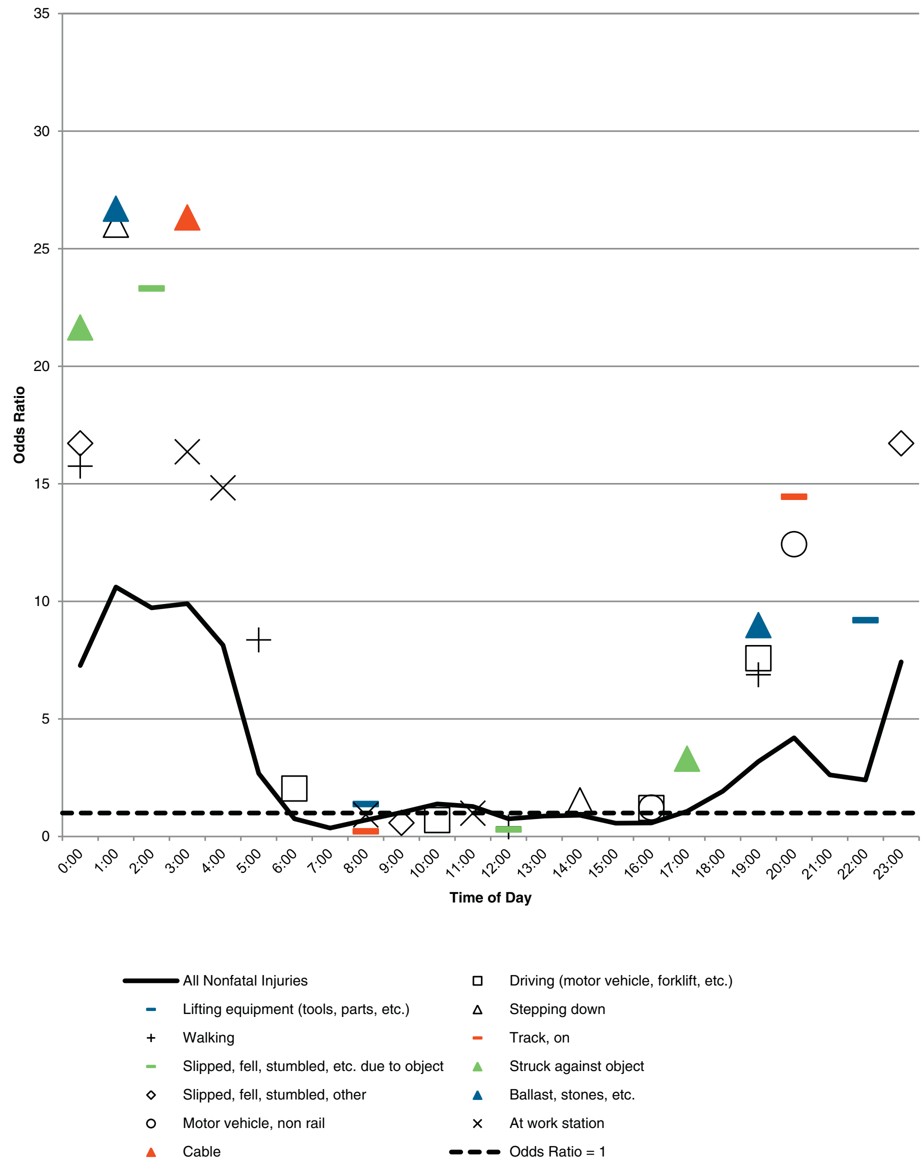

Fig. 8. Circumstances of nonfatal injury among signalmen.

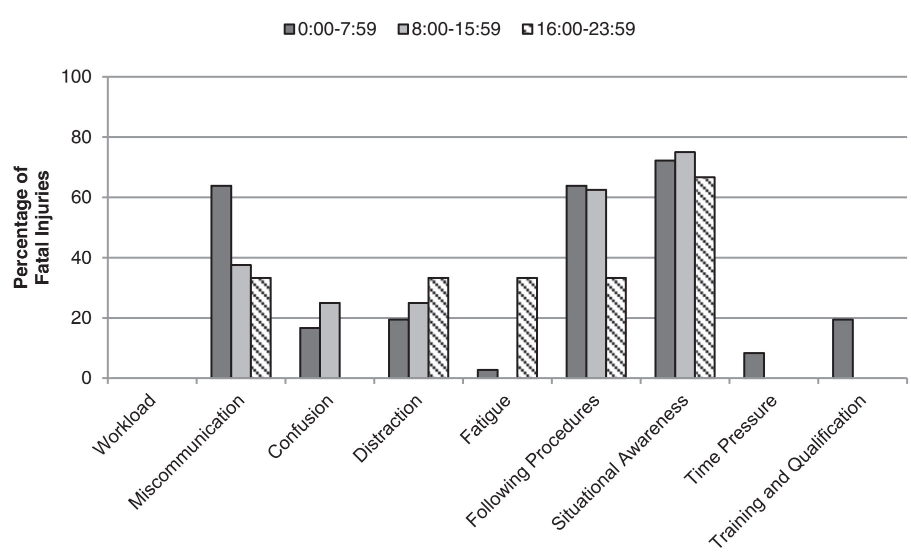

Fig. 9. Human factors analysis of MOW worker fatal injuries by shift.

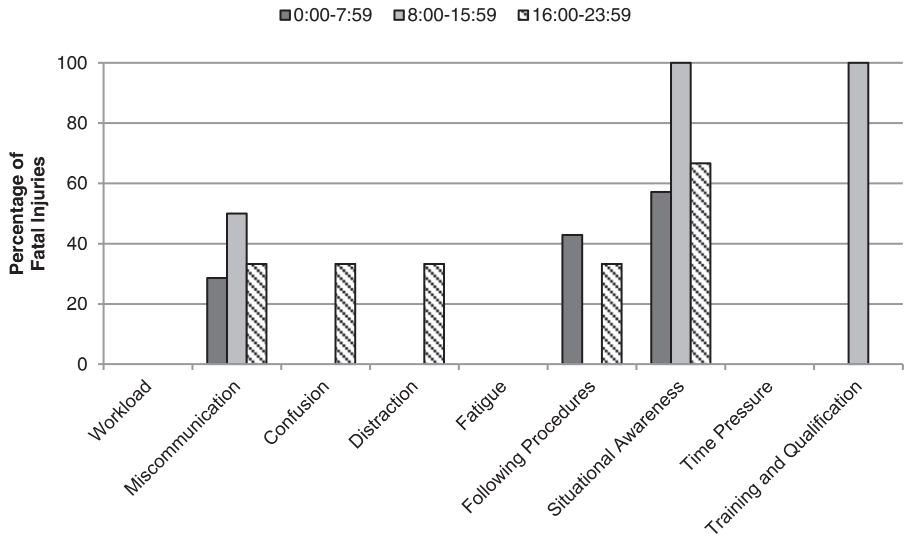

Fig. 10. Human factors analysis of signalmen fatal injuries by shift.

number of employees on shift. Gertler and Viale (2006a, 2006b) attribute reduced alertness to responding to nighttime emergency calls and overtime, particularly among signalmen. They found that MOW workers typically sleep less than the norm for U.S. adults, and to an extent this may degrade their performance. Data were not available to determine the contribution of these potential factors to the present results. However, data were available to explore other potential explanations.

Increasingly elevated odds of nonfatal injury between 19:00 and 24:00 suggest that the physiological effects of the circadian low phase are not entirely responsible for increased odds of injury during nighttime work. This period corresponds to the latter half of the second shift, consistent with an influence of time on task. However, the decreasing odds of nonfatal injury from early morning to the end of the third shift are not consistent with explanations based solely on time on task or on the duration of time since waking, and suggest that circadian effects may predominate during the circadian low phase.

The higher odds of injury during nighttime work corresponds to when substantially fewer employees are on duty, which could suggest a direct relationship between injuries and the presence of employees possibly because more employees are available to prevent mishaps. However, the percentage of employee hours worked varies little between 20:00 and 04:00 while the odds of injury range between approximately 2.4:1 and 10:1. Thus it does not appear that the number of employees at work has a direct effect on the odds of injury. Although time on task, circadian low phase, and number of employees on shift may all contribute to the observed elevated odds of injury during late night work, none of these explanations on their own appears to be sufficient to explain this effect. Other factors, like sleep debt among MOW employees, interrupted sleep in response to nighttime emergency calls, and, in general, work under dark or artificially lighted conditions also may contribute to the present findings of an increased risk of nonfatal injury at night. In contrast, daytime work (06:00 to 17:59) is associated with a relative odds of injury near or below 1:1.

Although this study only found an association between time of day and odds of injury, these time-of-day variations are consistent with reports of time of day effects on risk of job-related worker injuries in other industries. For MOW employees, who are not subject to hours of service regulations, they may in part reflect the duration of time since waking. Both MOW employees and signalmen respond to emergency calls when they would normally sleep (Gertler & Viale, 2006a, 2006b). The combination of circadian phase and these other conditions may contribute to a lack of alertness during work at night, resulting in higher odds of injury.

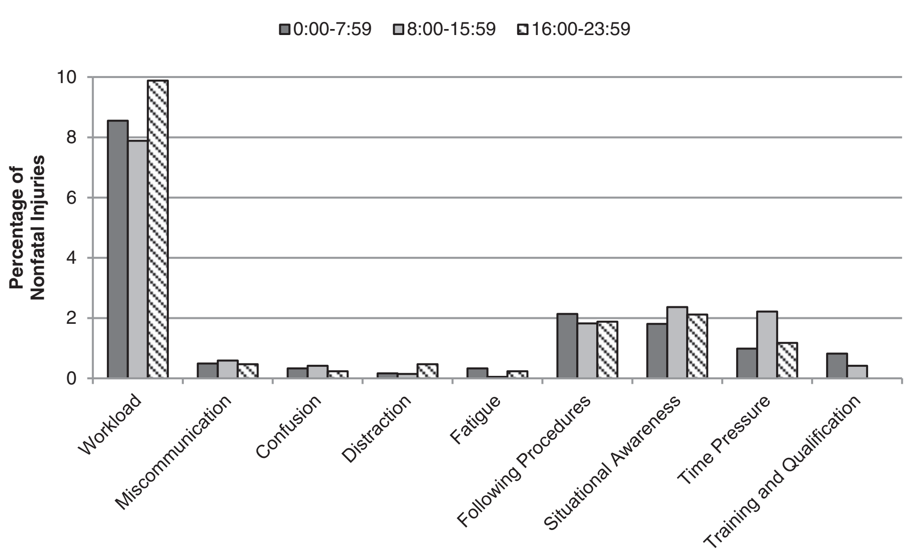

Fig. 11. Human factors contributing to MOW worker nonfatal injuries by shift.

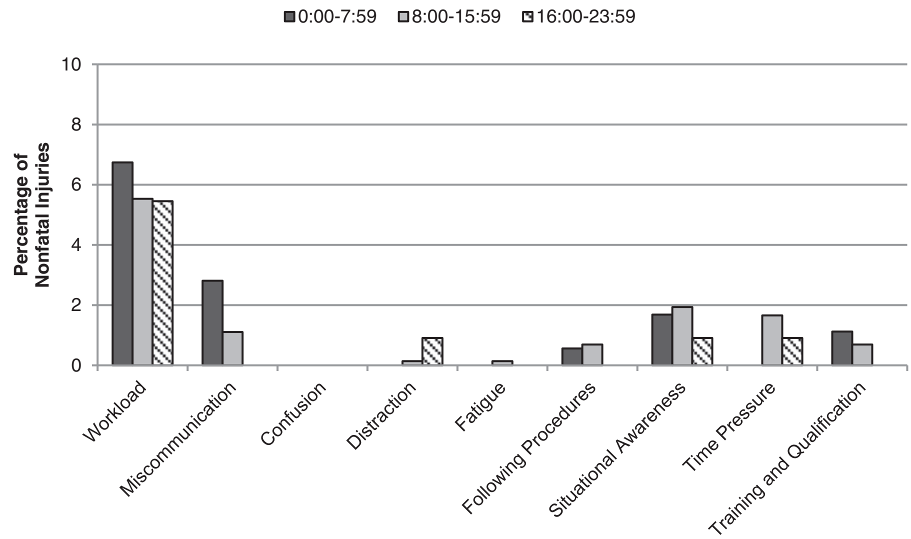

Fig. 12. Human factors contributing to signalmen nonfatal injuries by shift.

The time of day results are consistent with a two-process model of fatigue (e.g., Borbély & Achermann, 1999; Hursh et al., 2004), as modeled in the fit lines shown in Figs. 4–6. This model predicts the peak in injury odds during nighttime work and the much smaller magnitude relative peak around midday. Since the time of day with the highest frequency of injuries differs from the time of day with highest odds of injury (i.e., night), railroads can consider both times of day in designing interventions to prevent injuries based on the injury circumstances identified in this analysis. For example, both MOW employees and signalmen had higher odds of nighttime injuries when the circumstances involved non-rail motor vehicles or when walking. While a circadian rhythm model fits our data well, the circadian rhythm may not be the only factor. The increased odds of non-rail motor vehicle injury circumstances for MOW employees at 20:00 and for signalmen at 21:00 occurs earlier into the night than the typical late night peak in sleep-related vehicle accidents at 02:00 (Horne & Reyner, 1995), and earlier than one would expect to see a circadian rhythm effect. Possibly as a result of other factors such as darkness and work in artificial light, circumstances such as slips, trips, and falls were associated with the elevated the odds of injury at night for both railroad crafts.

The current study demonstrated the utility of analyzing both fatal and nonfatal injuries. Analysis of the much larger sample of nonfatal injuries in conjunction with data on time of exposure to roadway work provided a more detailed picture of the association between night work and MOW employee and signalmen injuries. This study found evidence of increased risk of injury at night and suggested circadian factors as explanation consistent with the data. This study also identified circumstances and human factors causes of injury that were particularly prevalent at night. Given this association between night work and risk of injury, new practices for nighttime work must be developed to adequately address fatigue and protect roadway workers from harm. The circumstances and contributing human factors identified here identify a starting point for developing new nighttime work practices.

5.1. Limitations

This study's estimates of exposure were the percentages of MOW employees and signalmen working at each hour of the day during a two-week period in 2006 (Gertler & Viale, 2006a, 2006b). Data from this brief period may not accurately represent the exposure of MOW employees and signalmen from 1997 to 2014. Also, as stated earlier, it was not possible to independently validate the attribution of the nonfatal injury data to human factors causes. A further limitation is in the possible misclassification or lack of consistency with which different railroads use circumstance codes when reporting injuries to the FRA.

5.2. Directions for future work

Future research should examine how roadway worker duties, locations, and the equipment that they use vary at different times of day. Research on the amount of time roadway workers spend on different tasks at different times of day could help to determine the types of work that are riskier to perform at night. Additional granularity in the analysis of human factors causes of fatal and nonfatal injuries could support specific countermeasures.

Acknowledgments

The U.S. Department of Transportation Federal Railroad Administration Office of Research and Development provided financial support for the reported study and authorized access to railroad employee fatality investigation reports. The opinions expressed in this article are the authors' own and do not necessarily reflect the views of the Federal Railroad Administration, the U.S. Department of Transportation, the Volpe National Transportation Systems Center, or the United States Government.

The authors thank the staff of the FRA Office of Safety and the National Archives Textual Branch for providing reports of employee fatality investigations.

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