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Research gaps and needs for preventing worker fatigue in the transportation and utilities industries

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Abstract

Background: The transportation and utilities industries include establishments engaged in the movement of passengers and freight, or the provision of public power, water, and other services. Along with the warehousing industry, they make up the US National Occupational Research Agenda's Transportation, Warehousing and Utilities (TWU) industry sector. In 2018 the sector composed 5% of the US workforce, with approximately 8 million workers. TWU workers experienced 19% of all fatalities among U.S. workers in 2018 and 7% of total occupational injuries and illnesses.

Methods: Around-the-clock operations, heavy workloads, long and irregular shifts, complicated schedules, and time pressures characterize work across the US TWU sector. However, there are considerable differences in worker priorities and concerns between TWU industries. Major areas

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W. Karl Sieber participated in the conception of this manuscript; the acquisition, analysis, and interpretation of data for the work; drafted and revised it critically for important intellectual content; had final approval of the version to be published; and agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Guang X. Chen participated in the conception of this manuscript; was responsible for the acquisition, analysis, and interpretation of data for the work; and drafted and revised it critically for important intellectual content. Gerald P. Krueger participated in the conception of this manuscript; contributed to the acquisition, analysis, and interpretation of data for the work; and drafted and revised it critically for important intellectual content. Jennifer E. Lincoln participated in the conception and design of this manuscript; contributed to the acquisition, analysis, and interpretation of data for the work; and drafted and revised it critically for important intellectual content. Cammie Chaumont Menéndez participated in the conception and design of this manuscript; contributed to the acquisition, analysis, and interpretation of data for the work; and drafted and revised it critically for important intellectual content. Mary B. O'Connor participated in the conception and design of this manuscript; contributed to the acquisition, analysis, and interpretation of data for the work; and drafted, reviewed, and revised it critically for important intellectual content.

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of concern within the sector include disparities in work schedules; required training for employee fatigue awareness and prevention; physical and mental job demands; and safety culture.

Results: Strategies for fatigue mitigation are critical to reduce the prevalence of injuries, safety-critical events, and crashes in TWU workers. Further research on the incidence and characterization of fatigue among TWU workers will guide the development of effective mitigation strategies. The influence of work scheduling on missed sleep opportunities and disrupted circadian rhythms should be determined. Evaluation of fatigue mitigation strategies can lead to the adoption of the most effective ones for each TWU industry.

Conclusion: Implementation of effective strategies is critical for the health, safety, wellbeing, and productivity of workers in the TWU sector.

Keywords

fatigue; fatigue mitigation; research needs; transportation; utilities

1 | INTRODUCTION

The transportation and utilities industries include establishments engaged in the movement of passengers and freight, or the provision of public power, water, and other services. Along with the warehousing industry, they make up the US National Occupational Research Agenda's Transportation, Warehousing and Utilities (TWU) industry sector. In 2018 the sector composed 5% of the US workforce, with approximately eight million workers.[1] TWU workers experienced 19% of all fatalities among US workers in 2018 and 7% of total occupational injuries and illnesses.[1]

Around-the-clock operations, heavy workloads, long and irregular shifts, complicated and varying schedules, and time pressures characterize work across the US TWU sector. However, there are considerable differences in worker priorities and concerns across TWU industries. Major areas of concern within the sector include disparities in work schedules; required training for employee fatigue awareness and prevention; physical and mental job demands; and safety culture.

The Working Hours, Sleep and Fatigue Forum[2] hosted by the US National Institute for Occupational Safety and Health (NIOSH) in September 2019 facilitated discussion of research gaps and needs around working hours, sleep, and fatigue specific to seven US industry sectors. This paper describes those findings for workers in the US transportation and utilities industries. It is not meant to be an exhaustive literature review, but rather, a description of the broad research on these concerns within the TWU sector. Recommendations for additional research are provided. Due to the paucity of research on work hours, sleep, and fatigue in the warehousing industry, this paper covers findings only in the US transportation and utilities industries of the TWU sector.

2 | FATIGUE IN TRANSPORTATION INDUSTRIES

2.1 | Air

Extensive research has been conducted on pilot fatigue,[3–12] particularly in aviation operations involving long-haul or ultra-long-haul routes,[13–17] and on jet lag and circadian rhythm disruption.[18–22] Fatigue awareness and prevention strategies have also been studied in airline pilots,[23–29] often with an emphasis on proactively identifying, managing, and mitigating fatigue.[30–33] However, fatigue in pilots flying for commuter and on-demand operations (14 CFR Part 135) and general aviation operations (14 CFR Part 91), has not been as exhaustively researched. These latter operations encompass a wide variety of aircraft, workload demands, flight environments, and missions. In addition to pilots, air traffic controllers and maintenance personnel who perform safety-critical functions are often impaired by fatigue stemming from insufficient or poor-quality sleep, circadian rhythm disruptions, and long duty periods.[24,34–36] Flight attendants have reported a higher prevalence of fatigue than the general population[37] and have been the subject of research on fatigue prevention training and comparison of international fatigue regulations. Regulations for working and rest hours for flight attendants in the United States were found to be among the least restrictive, and allowed a greater-than-typical risk of fatigue.[38–40]

Federal aviation regulations address fatigue management for pilots and flight attendants of large, passenger-carrying commercial aircraft by prescribing flight time limitations and required rest periods (14 CFR Part 117; 14 CFR § 121.467). Regulations do not provide similarly stringent limitations on work and rest hours for maintenance technicians who repair aircraft (14 CFR §121.377), although fatigue among maintenance workers has been linked to fatal aircraft crashes.[34] Mitigation strategies such as policies to reduce unexpected roster changes, decrease the frequency of individuals working longer than their rostered shifts, limit the hours of service (HOS), implement fatigue risk management systems, and education on fatigue causes, consequences, and countermeasures may limit the incidence of fatigue and fatigue-related maintenance errors and improve safety in aviation operations.[41,42]

2.2 | Trucking

The Federal Motor Carrier Safety Administration (FMCSA) has reported that driver fatigue has been identified as an important factor in large truck crashes.[43] However, estimates of the prevalence of crashes involving driver fatigue vary greatly due to different reporting practices and data sources.[44] In addition, driver fatigue can be difficult to identify during crash investigations, or investigators may not be trained to recognize signs of driver fatigue (e.g., lack of skid marks on the road behind an accident).[44]

A wide range in estimates in truck-driver-related motor vehicle crashes have been reported in the literature. Knipling and Wang[45] studied 1989–1993 General Estimates System (GES) and Fatality Analysis Reporting System (FARS) data of motor vehicle crash investigations based on police reports. The authors estimated that 1.4% of nonfatal crashes and 3.6% of fatal crashes were associated with driver drowsiness/fatigue (including both truck and passenger vehicle crashes). A study of 2018 FARS data suggested that 1.3% of fatal large truck crashes were attributed to truck driver sleepiness or fatigue.[46] While police investigations included in FARS data are one viable source of data for motor vehicle crashes, they may be an underestimation of the true prevalence of fatigue-related crashes since driver fatigue can be difficult to detect.[44]

The National Transportation Safety Board (NTSB) found that fatigue was the most frequently cited probable cause (31%) in fatal-to-truck-driver heavy truck crashes among 182 crash reports occurring in eight states between October 1, 1987, and September 30, 1988.[47] However, since fatal-to-truck-driver crashes represent only a small portion (approximately 18%)[48] of fatal large truck crashes, the NTSB estimate should not be applied to all fatal large truck crashes.[44] FMCSA's Large Truck Crash Causation Study (LTCCS) investigations of 963 fatal and nonfatal large truck crashes estimated that truck driver fatigue was judged to be present in 13% of truck crashes.[49,50] Of all LTCCS crashes where the truck was at-fault, asleep-at-the-wheel was the critical reason (CR), or immediate reason for the crash, in 7%.[50] As a percentage of all LTCCS crashes, truck driver asleep was the CR in 4%.[50] For all LTCCS multi-vehicle crashes where another vehicle was assigned the CR, as well as the critical event leading to the crash, asleep, was the CR in 9%.[50] In all, 8% of LTCCS crashes had a CR of asleep, assigned either to the truck driver or another driver.[50] A National Academies of Science, Engineering, and Medicine review of available data and studies reported that among the approximately 4000 fatalities resulting from crashes involving trucks and buses in the United States each year, 10%–20% of these crashes may have involved fatigued drivers.[44]

Commercial truck drivers, particularly those in long-haul freight delivery jobs, often operate in a work environment with multiple factors that are associated with lack of sleep, fatigue, and stress.[51] Insufficient sleep is associated with impaired cognitive performance, slowed reaction times, increased risk-taking behavior, and decreased overall driver situational awareness, increasing drivers' risk for fatigue-related crashes.[52] Fatigue is often related to work schedules, including long work hours, irregular work shifts, and being away from home for days or weeks at a time.[53] Driver schedules, and consequently time awake and on task, can be extended due to factors such as delays in loading and unloading, weather conditions, and traffic.[54–58] Time-pressured delivery commitments can increase driver stress and fatigue.[54,59–65] As a part of their workday, many commercial truck drivers engage in considerable physical activity when they are not actually driving, such as loading or unloading their own trucks (e.g., making grocery deliveries to stores, moving household goods, and many others). At times, such physical activity can offer a stimulating effect to promote subsequent driving alertness; whereas in other instances such strenuous work can be tiring (both physiologically and cognitively) and hasten the onset of fatigued driving.[66,67] Additionally, drivers are often paid by the mile driven instead of by hours worked, creating psychological stress and pressures to push their hours of work.[68–70]

While driving and rest times are regulated by FMCSA hours of ervice (HOS) regulations (49 CFR Part 395), there are individual-level factors among truck drivers which increase the risk for fatigue-related crashes. Long-haul truck drivers have a high prevalence of obesity (69%), hypertension (26%), and diabetes (14%),[60,71–74] all of which tend to be comorbid with the high prevalence (at least 21%) of obstructive sleep apnea (OSA), a sleep disorder associated with driver fatigue.[75,76] One of the most significant remaining research gaps is the need to identify the true incidence rate of OSA and to develop proactive strategies for resultant sleep-deprivation and driver fatigue.[44] There are also individual differences in susceptibility to fatigue due to age, gender, alcohol consumption, and personal traits.[77] Males and young drivers are at higher risk of fatigue than their counterparts. Further development of methods to identify individual differences in fatigue susceptibility is needed.[78]

2.3 | Urban transit and ground passenger

The transit industry provides service from early morning to late night, often with 24-h service, to meet the needs of the public ridership. Ground passenger transportation provides on-demand service (e.g., taxis or uber-like transportation) with demands that bridge the gap between what is offered by public transit and the passengers' specific destinations. Bus drivers working as fill-ins or substitutes for extra board or on-call often get little time off between assignments for rest. Many public transit agencies require bus and train operators to work split shifts. Transit operator fatigue management programs are not systematically applied and their operation needs to be reinforced repeatedly by agencies.[79] The Bureau of Labor Statistics finds that transportation-related incidents are the leading cause of fatalities (55%) in the urban transit and ground passenger industry in the United States.[80] Little data are available to quantify the burden of fatigue on fatalities. Blower and Green[81] noted that being drowsy or asleep was only noted as a driver error in 1.1% of 2252 fatal bus crashes between 1999 and 2005. Bus driver fatigue was cited only once as an associated factor in 40 fatal bus accidents included in the Bus Crash Causation Study.[82]

International studies of taxi drivers and other passenger drivers-for-hire focus on the prevalence of fatigue-related outcomes (e.g., driving while tired, motor vehicle collisions) and risk factor identification. Established epidemiologic associations are between fatigue and motor vehicle collisions or near misses,[83–90] with shift timing,[89,90] length of working time,[87–94] and insufficient rest periods[87,90,91,95] the most frequently identified risk factors. Other risk factors include pay structure,[89] caffeine use,[90,92] optimism bias where drivers are unaware of their fatigue level,[86,91 95] deficient sleep time or quality,[88,92] working an additional job,[92] poor safety climate, high perceived job demands, and workplace violence[94] and emotional demands.[96]

The starting point for addressing fatigue-related risks are HOS limitations for passenger-carrying vehicles, including buses, that are set by federal regulation (49 CFR Part 395). Published studies on bus operator fatigue are focused on work shifts and fatigue-related outcomes, specifically, epidemiologic associations between split shifts and alertness,[97] drowsiness,[97] sleepiness[97,98] and fatigue,[98] alternating shifts and sleepiness,[99,100] night shifts, working hours, and motor vehicle collisions,[101] and shift work, working hours, and fatigue (with a calculated risk index).[100] Research examining fatigue as a risk factor for motor vehicle collisions[102,103] and sleep disorders[104,105] is also found in the scientific literature.

The ground transportation industry is less regulated with respect to fatigue prevention or mitigation. HOS limitations are generally the starting point for best practices. Fatigue mitigation is limited to HOS and is typically promulgated at the municipal level, with a focus on limiting drivers to a maximum of work hours per shift over a 7-day workweek. To the knowledge of the authors epidemiologic research evaluating the effectiveness of HOS laws is not available in the scientific literature.

2.4 | Rail

Federal regulations provide for HOS limitations for workers in train or engine service (engineers, trainmen, hostlers, conductors, etc.) (49 CFR § 228.11) and for train operators for commuter or intercity passenger operations (49 CFR § 228.405). Rail operators frequently have inadequate rest or sleep from commuting between their place of work and their homes. Operators on extra board on-call status accumulate more overtime and, ultimately, more sleep loss and fatigue. Research suggests railroad workers with fatigue have an increased risk of human-factors-related incidents (e.g., collisions, derailments, near misses, or missing signals).[79,106,107] Workers in railroad dispatching centers may be in regular, relief, or extra board job status, and are also subject to fatigue.[108]

The US railroad industry aims to manage fatigue-related risk in operations through a combination of educational efforts, adjustments to work schedules, sleep disorder screening programs, collaborations in development of biomathematical models of fatigue and alertness,[108] and experimentation with technological aids to fatigue management.[109,110]

2.5 | Seafaring and inland waterways

Seafaring is an isolated and confined work environment on a 24-h work schedule which can affect the mental state and physical fatigue experienced by workers at sea.[111] Fatigue has been implicated in 16% of vessel accidents and 33% of personal injury accidents.[111] Crewmembers on vessels subject to US manning requirements must receive a minimum of 10 h rest in any 24 h (46 CFR.15.1111).

There is a paucity of studies of workers on passenger or freight-carrying seafaring commercial vessels and fatigue. For decades, the US Navy conducted research into alternative crew watch schedules, examined sleep patterns of sailors aboard Navy warships and submarines, and attempted to shift the timing of sleep to ensure alert and safe operations at sea.[112] Crew numbers become smaller as new ship design and automation technologies advance, affecting sailor workload and cognitive fatigue from the vigilance required when working around automated technologies. Although the work has modernized, the issues relating to fatigue and safety remain, and research in this field continues to be warranted.

The U.S. Coast Guard (USCG) promotes HOS limits for Inland Waterways Towboat and Barge Operations (US Code 8904c). Towboat crews generally stay on board for about 28 days of continuous operations, followed by 2 weeks off-duty. A preferred practice is for crews to alternate 6-h shifts (square watch system of 6-on, 6-off, 6-on, 6-off), for totals of 12-h on-duty and 12-h off each 24-h day, and employing a split-sleep schedule. While published research on the health of towboat and barge shipping workers is not available, obesity has been found to be prevalent among wheelhouse crew.[113] The USCG developed a Crew Endurance Management System to identify and manage operational risk factors, although few carriers take advantage of it.[114] The system evaluates crew endurance and management through a range of environmental, physiological, operational, and psychological risk factors such as irregular work periods, temperature extremes, heavy workloads, and extended separation from family members,[115,116] and provides light-management techniques to match energy levels with time-of-day, practical recommendations for controlling operational risk factors, and guidance on plan design and implementation.[114]

2.6 | Fatigue in the utilities industry

Split, weekend, and night shifts are common for utilities workers who may experience long shifts (longer than 8-h) and extended working hours (longer than 10-h). Many of these workers work on-call to fill in shifts, especially during emergency operations. Little warning or time to plan rest or recovery periods often results in varying sleep duration and timing. Shift work, especially rotating shift schedules, and the incumbent difficulties caused by circadian biological disruptions readily lead to poorer performance.[117] Rosa and Bonnet[118] found that after 10 months adaptation from an 8-h/5–7-day shift schedule to a 12-h/2–4-day (8 or 12-h rotating day and night schedules) shift schedule, workers in a natural gas utility reported higher subjective workloads on 12-h shifts compared to 8-h shifts. More frequent reaction time misses and hand tremors among these workers seen during the 12-h shifts were considered attributable to the extra 4-h on the extended shift.[118] Measures of circadian fluctuations in performance and subjective state showed decreases at night, with the worst performances after the 12-h shift schedule. Extra caution was recommended when scheduling critical activities during extended work shifts, especially night shifts, with attention given to staffing levels, workload, job rotation, environmental exposures, emergency contingencies, rest breaks, commuting time, and social/domestic responsibilities.[119]

Additional risk factors for fatigue among utilities workers are long commutes from home or to distant work sites in times of emergency and for restoration of utility services.[120] Fatigue may compound other hazards, since workers often deal with dangerous agents and conditions such as electricity, natural gas, chemicals, hazardous waste, extreme heights, or extreme weather conditions. A survey of electrical transmission and distribution-line construction workers found extreme temperatures and long shifts were perceived as principal causes of fatigue.[121] These results suggest that findings from fatigue-laboratory research may not directly apply to utility workers' perceptions of causes of fatigue. The joint effects of fatigue and working in extreme temperatures as well as in diverse or unfamiliar surroundings should be evaluated.

In the nuclear power industry, maintaining alertness for control room operators at all times is critical. Factors affecting operator performance include shift schedules, caffeine and alcohol use, diet, family lifestyle factors, control room working environment, staffing and overtime practices, and work task design.[122] In a study of five safety indicators among nuclear plant workers, operator overtime was found to be significantly related to plant safety performance but use of a 12-h shift schedule was correlated only with one metric, operator error.[123] The US Nuclear Regulatory Commission recognizes operator fatigue in the nuclear power industry and has developed guides for managing personnel fatigue.[124–126]

Further delineation of the influence of work hours and worker fatigue is warranted in this subsector. Reliable data are limited and there is a need for broader research concerning utilities workers and adequate sleep, work shift length, and involuntary overtime; assessment of environmental factors such as high temperatures in the workplace; and the incidence of heavy workloads.

2.7 | Research needs to reduce fatigue risks

The NIOSH Working Hours, Sleep and Fatigue Forum identified disparate research gaps and needs within the US TWU sector.

2.8 | Data needs

Surveillance studies provide baseline data on the incidence of fatigue and associated risk factors. Fatigue identified in workers such as aviation maintenance technicians, seafarers, transit drivers, utilities workers, bus and truck drivers, and warehouse workers need further examination. Baseline studies for these occupations can determine the contribution of operator fatigue to work performance and safety. They also will provide data for evaluation of approaches to managing fatigue-related safety risks.[127,128]

2.9 | Specific issues

The impact of the working environment on fatigue should be evaluated. Contributors within the work environment include long or irregular work hours; extended and variable work schedules; time pressure; work in diverse or unfamiliar surroundings; environmental conditions; and psychological stress such as time away from home.[53] Long hours and shifts may exacerbate physical and mental health disorders or disrupt circadian rhythms, which can affect sleep and increase worker fatigue. Kudo and Belzer[129] note that the relationship between employment attributes, such as method and level of compensation, and worker fatigue is not well understood. Pressures from gig work, where workers such as couriers are paid on a piece-rate or “gig,” may cause anxiety and fatigue from greater physical and mental workloads in the 24/7 economy.[130,131]

Many factors that cause or contribute to fatigue occur in combination in TWU workers. Mitigation of all possible causes of fatigue may not be feasible. Control of many of the predominant risk factors or groups may be more feasible. Efforts to develop tools for detecting and measuring drowsiness have advanced and should continue.[132–134]

The emergence of onboard safety monitoring systems including real-time fatigue detection technologies and mandatory use of electronic logging devices in the United States (effective on December 16, 2019) provide new opportunities to measure driving time and truck driver fatigue objectively and in real-time. Most previous studies used self-report data to measure driver fatigue and driver time. The onboard fatigue and behavior measurement technologies use machine learning and pattern recognition technologies to detect fatigued and distracted driving behaviors. The technologies can also provide feedback to drivers and managers, which can potentially reduce fatigued driving.[132–134] The FMCSA is planning to employ data that are collected from onboard safety monitoring systems in its updated study of contributing factors to crashes involving large commercial trucks.[135]

Better understanding of diagnosis and treatment for OSA can help to develop best practices for detection and treatment of OSA. OSA varies in terms of severity on a continuum from mild to moderate to severe apnea. It is not clear how apnea impacts operator fatigue, and to what degree. More research is needed to determine at what point (i.e., diagnosed mild, moderate, or severe apnea) safety preventive measures (such as continuous positive airway pressure (CPAP)) should be imposed.

2.10 | Program evaluation and implementation needs

Fatigue mitigation in industries such as aviation, trucking, and rail transportation has been accomplished with regulated HOS or duty, and rest times. The effectiveness of this approach should be determined. An alternative means of compliance to HOS has been development of Fatigue Risk Mitigation Systems (FRMS). FRMS guidelines are proposed by the operator rather than by regulation. FRMS are considered better aligned with overall system performance.[127] Gander et al.[127] point out that a FRMS or endurance management systems can determine not only how fatigue affects safety, but also may help to build a business case for such a system. Fatigue risk management guidelines and fatigue management strategies are being developed for the utilities industry.[136,137] They are already in use for some occupations in air,[138–140] ground,[141,142] and sea transportation.[114] Implementation of fatigue management systems or other successful interventions should be encouraged in other industries.[143,144] Other tools to address causes and consequences of fatigue may include wellness programs, fatigue self-assessment, and fatigue prevention training in organizational health and welfare programs. These tools can inform organizational safety culture and fatigue management policy.

Barriers to implementation of an effective FRMS should also be determined. Changes in fatigue levels due to fatigue management as well as organizational benefits, worker acceptance, process changes, and costs should be considered. An example is the evaluation of the effectiveness of the North American Fatigue Management program (NAFMP) in reducing commercial truck driver fatigue.[42] The NAFMP (www.nafmp.org) was designed to enhance carriers' and drivers' ability to effectively deal with the challenges of fatigue through training, use of technologies, sleep disorder screening and treatment. The NAFMP was developed by international partnerships between multiple jurisdictions (FMCSA and Transport Canada) and motor carrier stakeholder groups. NIOSH is conducting a longitudinal observational cohort study to evaluate the effectiveness of NAFMP in reducing commercial truck driver fatigue.

Implementation, evaluation, and dissemination of best practices for an effective fatigue mitigation plan will improve health and safety for all TWU workers. Sharing guidance and evidence-based solutions from such studies will allow for broader support for fatigue mitigation FRMS systems, and allow policymakers, regulators, management, and workers to adopt and implement fatigue mitigation strategies.

3 | CONCLUSION

Society's expectations for 24-h-7-days-per-week operations are evident in the TWU sector, where heavy workloads, long hours, irregular shifts, complicated and varying schedules, and time pressure may subject workers to inadequate rest periods, decreased sleep opportunities, and disrupted circadian cycles. These can result in worker fatigue and impaired cognitive and physical performance on the job, increasing the risks for fatigue-related worker errors, accidents, injuries, and illnesses. Further research into the incidence and characterization of fatigue, as well as into the adaptation, implementation, and evaluation of strategies for fatigue mitigation are critical for the health, safety, wellbeing, and productivity of workers in the TWU sector.

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DISCLAIMER

The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, and should not be construed to represent any agency determination or policy.

DATA AVAILABILITY STATEMENT

Data derived from public domain resources. The data that support the findings of this study are available online. See references [1–144] for Internet access to the source material.

REFERENCES

1. National Institute for Occupational Safety and Health (NIOSH). Current U.S. workforce data by NORA sector; 2018. Accessed February 18, 2021. https://www.cdc.gov/niosh/topics/surveillance/default.html
2. Wong IS, Swanson N. NIOSH Working hours, sleep and fatigue forum: a recap and future directions, https://blogs.cdc.gov/niosh-science-blog/2019/10/07/fatigue-forum/
3. Berberich J, Leitner R. The look of tiredness: evaluation of pilot fatigue based on video recordings. APAHF. 2017;7(2):86–94. doi:10.1027/2192-0923/a000122
4. Caldwell JA. The impact of fatigue in air medical and other types of operations: a review of fatigue facts and potential counter-measures. Air Med J. 2001;20:25–32.
5. Caldwell JA. Fatigue in aviation. Travel Med Infect Dis. 2005;3:85–96. doi:10.1016/j.tmaid.2004.07.008 [PubMed: 17292011]
6. Co EL, Gregory KB, Johnson JM, Rosekind MR. Crew factors in flight operations XI: a survey of fatigue factors in regional airline operations. NASA TM 208799. Moffett Field, CA: NASA Ames Research Center; 1999. Accessed April 20, 2020. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20000032967.pdf
7. Jackson CA, Earl L. Prevalence of fatigue among commercial pilots. Occ Med. 2006;56(4):263–268. doi:10.1093/occmed/kql021
8. Honn KA, Satterfield BC, McCauley P, Caldwell JL, Van Dongen HPA. Fatiguing effect of multiple take-offs and landings in regional airline operations. Accident Anal Prev. 2016;86:199–208. doi:10.1016/j.aap.2015.10.005
9. Seungyoung L, Kim JK. Factors contributing to the risk of airline pilot fatigue. JATM. 2018;67:197–207. doi:10.1016/j.jairtraman.2017.12.009
10. National Research Council. The Effects of Commuting on Pilot Fatigue. The National Academies Press; 2011.

11. Powell DMC, Spencer MB, Holland D, Broadbent E, Petrie KJ. Pilot fatigue in short-haul operations: effects of number of sectors, duty length, and time of day. Aviat Space Environ Med. 2007;78(7):698–701. [PubMed: 17679568]
12. Rosekind MR, Co EL, Gregory KB, Miller DL. Crew factors in flight operations XIII: a survey of fatigue factors in corporate/executive aviation operations. NASA TM 209610. Moffett Field, CA: Ames Research Center; 2000. https://ntrs.nasa.gov/api/citations/20010039028/downloads/20010039028.pdf
13. Cabon P, Bourgeois-Bougrine S, Mollard R, Coblentz A, Speyer JJ. Electronic pilot-activity monitor: a countermeasure against fatigue on long-haul flights. Aviat Space Environ Med. 2003;74(6):679–682. [PubMed: 12793543]
14. Dinges DF, Graeber RC, Connell LJ, Rosekind MR, Powell JW. Fatigue-related reaction time performance in long-haul flight crews. Sleep Res. 1990;19(1990):117.
15. Flower DJC. Alertness management in long-haul flying. Transp Res Part F Traffic Psychol Behav 2001;4(1):39–48. doi:10.1016/S1369-8478(01)00012-2
16. Holmes A, Al-Bayat S, Hilditch C, Bourgeois-Bougrine S. Sleep and sleepiness during an ultra long-range flight operation between the Middle East and United States. Accident Anal Prev. 2012;45:27–31. doi:10.1016/j.aap.2011.09.021
17. Roach GD, Petrilli RMA, Dawson D, Lamond N. Impact of layover length on sleep, subjective fatigue levels, and sustained attention of long-haul airline pilots. Chronobiol Int. 2012;29(5):580–586. doi:10.3109/07420528.2012.675222 [PubMed: 22621354]
18. Gander PH. Myhre G, Graeber RC, Anderson HT, Lauber JK. Crewfactors in Flight Operations I: effects of 9-hour time zone changes on fatigueand the circadian rhythms of sleep/wake and core temperature. NASA TM-88197. Moffett Field, CA: NASA Ames Research Center; 1985.
19. Gander PH. Mulrine HM, van den Berg MJ, et al. Pilot fatigue: relationships with departure and arrival times, flight duration, and direction. Aviat Space Environ Med. 2014;85(8):833–840. doi:10.3357/ASEM.3963.2014 [PubMed: 25199126]
20. Gander PH, Mulrine HM, van den Berg MJ, et al. Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. J Sleep Res. 2014;24:110–119. doi:10.1111/jsr.12197 [PubMed: 25082509]
21. National Aeronautics and Space Administration (NASA). Pilot fatigue and circadian desynchronosis: report of a workshop held in San Francisco, California, on August 26-28, 1980. Accessed August 10, 2020. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19810012516.pdf
22. Samuel A, Wegman HM, Vejvoda M. Jet lag and sleepiness in air crew. J Sleep Res. 1995;4:30–36. 10.1111/j.1365-2689.1995-tb00223.x
23. Civil Aviation Authority. A review of in-flight napping strategies. Accessed August 2, 2020. https://publicapps.caa.co.uk/docs/33/2003_08.PDF
24. Caldwell JA, Mallis MM, Caldwell JL, Paul MA, Miller JC, Neri DF. Fatigue countermeasures in aviation. Aviat Space Environ Med. 2009;80:29–59. doi:10.3357/ASEM.2435.2009 [PubMed: 19180856]
25. Petrie KJ, Powell D, Broadbent E. Fatigue self-management strategies and reported fatigue in international pilots. Ergonomics. 2004;47:461–468. doi:10.1080/0014013031000085653 [PubMed: 15204298]
26. Rosekind MR, Smith RM, Miller DL, et al. Alertness management: strategic naps in operational settings. J Sleep Res. 1995;4:62–66. doi:10.1111/j.1365-2869.1995.tb00229.x/ [PubMed: 10607214]
27. Signal TL, Gander PH, van den Berg MJ, Graeber RC. In-flight sleep of flight crew during a 7-hour rest break: implications for research and flight safety. Sleep. 2013;36(1):109–115. doi:10.5665/sleep.2312 [PubMed: 23288977]
28. van Drongelen A, van der Beek AJ, Hlobil H, Smid T, Boot CR. Development and evaluation of an intervention aiming to reduce fatigue in airline pilots: design of a randomised controlled trial. BMC Public Health. 2013;13:776. doi:10.1186/1471-2458-13-776 [PubMed: 23971514]
29. Weir JD. Three phase approach to solving the bidline generation problem with an emphasis on mitigating pilot fatigue through circadian rule enforcement. Report number CI02-782. Wright

Patterson Air Force Base: U.S. Air Force; 2002. Accessed August 2, 2020. https://apps.dtic.mil/dtic/tr/fulltext/u2/a410818.pdf

30. International Air Transport Association (IATA). Fatigue safety performance indicators (SPIs): a key component of proactive fatigue hazard identification; 2014. Accessed August 2, 2020. http://www.iata.org/whatwedo/ops-infra/Documents/fatigue-spis_a-key-component-of-proactive-fatigue-hazard-identification.pdf
31. Perhinschi MG, Smith B, Betoney P. Fuzzy logic-based detection scheme for pilot fatigue. Aircr Eng Aerosp Technol. 2010;82(1):39–47. doi:10.1108/00022661011028100
32. Vejvoda M, Elmenhorst E-M, Pennig S, et al. Significance of time awake for predicting pilots' fatigue on short-haul flights: implications for flight duty time regulations. J Sleep Res. 2014;23(5):564–567. doi:10.1111/jsr.12186 [PubMed: 25040665]
33. Wu EQ, Peng XY, Zhang CZ, Lin JX, Sheng RSF. Pilots' fatigue status recognition using deep contractive autoencoder network. IEEE Trans Instrum Meas. 2019;68(10):3907–3919. doi:10.1109/TIM.2018.2885608
34. National Transportation Safety Board (NTSB). Loss of control Sundance Helicopters, Inc. Eurocopter AS350-B2, N37SH near Las Vegas, Nevada December 7, 2011. Aircraft Accident Report NTSB/AAR-13/01; 2013. Accessed April 20, 2020. https://ntsb.gov/investigations/AccidentReports/Reports/AAR1301.pdf
35. Cruz C, Della Rocco P, Hackworth C. Effects of quick rotating shift schedules on the health and adjustment of air traffic controllers. Aviat Space Environ Med. 2000;71(4):400–407. [PubMed: 10766465]
36. Cruz CE, Della Rocco PS. Sleep patterns in air traffic controllers working rapidly rotating shifts: a field study. Report DOT/FAA/AM-95/12. Washington, DC: Federal Aviation Administration; 1995.
37. McNeely E, Mordukhovich I, Tideman S, Gale S, Coull B. Estimating the health consequences of flight attendant work: comparing flight attendant health to the general population in a cross-sectional study. BMC Public Health. 2018;18(1):346. doi:10.1186/s12889-018-5221-3 [PubMed: 29566648]
38. Avers KE, Hauck EL, Blackwell LV, Nesthus TE. A qualitative and quantitative analysis of fatigue countermeasures training in the aviation industry. Int J Appl Aviat Stud. 2010;10(2):51–66.
39. Banks JO, Avers KE, Nesthus TE, Hauck EL. A comparative study of international flight attendant fatigue regulations and collective bargaining agreements. J Air Transport Management. 2012;19:21–24. doi:10.1016/j.jairtraman.2011.12.003
40. Hauck EL, Avers KB, Banks JO, Blackwell LV. Evaluation of a fatigue countermeasures training program for flight attendants. Report DOT/FAA/AM-11/18. Washington, DC: Federal Aviation Administration; 2011.
41. Signal TL, van den Berg MJ, Mulrine HM. Personal and work factors that predict fatigue-related errors in aircraft maintenance engineering. Aerosp Med Hum Perform. 2019;90(10):860–866. doi:10.3357/amhp.5000.2019 [PubMed: 31558194]
42. Hobbs A, Avers KB. Hiles JJ. Fatigue risk management in aviation maintenance: current best practices and potential future counter-measures. Report DOT/FAA/AM-11/10, Washington, DC: FederalAviation Administration; 2011. https://rosap.ntl.bts.gov/view/dot/20808
43. Federal Motor Carrier Safety Administration (FMCSA). Large Truck Crash Causation Study (LTCCS) Analysis Series: Using LTCCS Data for Statistical Analyses of Crash Risk. Publication No. FMCSA-RI-05-037. Washington, DC: Federal Motor Carrier Safety Administration; 2006. https://www.fmcsa.dot.gov/safety/research-and-analysis/large-truck-crash-causation-study-ltccs-analysis-series-using-ltccs
44. National Academies of Sciences, Engineering, and Medicine. Commercial Motor Vehicle Driver Fatigue, Long-Term Health, and Highway Safety: Research Needs. The National Academies Press; 2016. doi:10.17226/21921
45. Knipling RR, Wang J-S. Crashes and Fatalities Related to Driver Drowsiness/Fatigue. National Highway Traffic Safety Administration (NHTSA); 1994.
46. Federal Motor Carrier Safety Administration (FMCSA). Large Truck and Bus Crash Facts 2019. Publication No. FMCSA-RRA-20-055. Washington, DC: Federal Motor Carrier Safety

Administration; 2021. Accessed December 22, 2021. https://www.fmcsa.dot.gov/safety/data-and-statistics/large-truck-and-bus-crash-facts-2019

47. National Transportation Safety Board (NTSB). Safety study: Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes (volume 1). Report No. NTSB/SS-90/01. Washington, DC: National Transportation Safety Board; 1990.
48. Federal Motor Carrier Safety Administration (FMCSA). 2019 Pocket Guide to Large Truck and Bus Statistics. Publication No. FMCSA-RRA-19-012. Washington, DC: Federal Motor Carrier Safety Administration; 2020; 2019. Accessed May 13, 2020. https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/2020-01/FMCSA_Pocket_Guide_2019-FINAL-1-9-2020.pdf
49. Federal Motor Carrier Safety Administration (FMCSA). The large truck crash causation study–analysis brief. Publication No. FMCSA-RRA-07-017. Washington, DC: Federal Motor Carrier Safety Administration; 2007. Accessed August 10, 2020. https://www.fmcsa.dot.gov/safety/research-and-analysis/large-truck-crash-causation-study-analysis-brief
50. Starnes M. Large-truck crash causation study: an initial overview. Publication No. DOT HS 810 646. Washington, DC: National Highway Traffic Safety Administration; 2006. https://crashstats.nhtsa.dot.gov/api/public/viewpublication/810646
51. Apostolopoulos Y, Sonmez S, Hege A, Lemke MK. Work strain, social isolation and mental health of long-haul truckers. Occup Ther Ment Health. 2016;32(1):50–69. doi:10.1080/0164212x.2015.1093995
52. Matthews G, Saxby DJ, Funke GJ, Emo AK, Desmond PA. Driving in states of fatigue or stress. In: Caird J, Lee J, eds. Handbook of Driving Simulation for Engineering, Medicine and Psychology. CRC Press; 2011:29-1-29-11.
53. Härmä M. Workhours in relation to work stress, recovery and health. Scand J Work Environ Health. 2006;32(6):502–514. doi:10.5271/sjweh.1055 [PubMed: 17173206]
54. Braver ER, Preusser CW, Ulmer RG. How long-haul motor carriers determine truck driver work schedules: the role of shipper demands. J Safety Res. 1999;30(3):193–204. 10.1016/S022-4375(99)00014-6
55. Chen GX, Sieber WK, Lincoln JE, et al. National survey of U.S. long-haul truck drivers: injury and safety. Accident Anal Prev. 2015;85:66–72. doi:10.1016/j.aap.2015.09.001
56. Bunn TL, Slavova S, Struttmann TW, Browning SR. Sleepiness fatigue and distraction/inattention as factors for fatal versus nonfatal commercial motor vehicle driver injuries. Accid Anal Prev. 2005;37(5):862–869. doi:10.1016/j.aap.2005.04.004 [PubMed: 15921653]
57. Bunn TL, Yu L, Slavova S, Bathke A. The effects of semi-truck driver age and gender and the presence of passengers on collisions with other vehicles. Traffic Inj Prev. 2009;10(3):266–272. doi:10.1080/15389580902857622 [PubMed: 19452368]
58. Stevenson M, Sharwood LN, Wong K, et al. The heavy vehicle study: a case-control study investigating risk factors for crash in long distance heavy vehicle drivers in Australia. BMC Public Health. 2010;10(1):162. doi:10.1186/F1471-2458-10-162 [PubMed: 20338064]
59. National Transportation Safety Board (NTSB). NTSB 2019-2020 most wanted list of transportation safety improvements; 2020. Accessed on May 13, 2020. https://www.ntsb.gov/safety/mwl/Pages/default.aspx
60. Sieber WK, Robinson CF, Birdsey J, et al. Obesity and other risk factors: the national survey of U.S. long-haul truck driver health and injury. Am J Ind Med. 2014;57(6):615–626. doi:10.1002/ajim.22293 [PubMed: 24390804]
61. Bureau of Labor Statistics (BLS). Occupational outlook handbook; 2020. Accessed May 13, 2020. https://www.bls.gov/ooh/transportation-and-material-moving/heavy-and-tractor-trailer-truck-drivers.htm
62. Hege A, Perko M, Johnson A, Yu CH, Sonmez S, Apostolopoulos Y. Surveying the impact of work hours and schedules on commercial motor vehicle driver sleep. Saf Health Work. 2015;6:104–113. doi:10.1016/j.shaw.2015.02.001 [PubMed: 26106509]
63. Apostopoulos Y, Sönmez S, Shattell MM. Worksite-induced morbidities among truck drivers in the United States. J Amer Assoc Occup Health Nurses. 2010;58(7):285–296. doi:10.3928/08910162-20100625-01

64. Apostopoulos Y, Sönmez S, Shattell MM, Gonzales C, Fehrenbacher C. Health survey of U.S. long-haul truck drivers: work environment, physical health, and healthcare access. Work. 2013;46(1):113–123. doi:10.3233/WOR-121553 [PubMed: 23324711]
65. Hanowski RJ, Hickman J, Fumero MC, Olson RL, Dingus TA. The sleep of commercial vehicle drivers under the 2003 hours-of-service regulations. Accid Anal Prev. 2007;39(6):1140–1145. doi:10.1016/j.aap.2007.02.011 [PubMed: 17920836]
66. O'Neill TR, Krueger GP, Van Hemel SB, McGowan AL, Rogers WC. Effects of cargo loading and unloading on truck driver alertness. Transp Res Rec. 1999;1686:42–48. 10.3141/1686-07
67. O'Neill TR, Krueger GP, Van Hemel SB, McGowan AL. Effectsof operating practices on commercial driver alertness. FHWA-OMC Technical Report No. FHWA-MC-99-140. Washington, DC: Federal Highway Administration; 1999.
68. Faulkiner MR, Belzer MH. Returns to compensation in trucking: does safety pay? Econ Labour Relat Rev. 2019;30(2):262–284. doi:10.1177/1035304619833859
69. Belzer MH, Saltzman GM. The case for strengthened motor carrier hours of service regulations. Transp J. 2002;41(4):51–71.
70. Quinlan M, Wright L. Remuneration and safety in the Australian heavy vehicle industry: a review undertaken forthe National Transport Commission. Project Report. Melbourne, Australia: National Transport Commission; 2008; Accessed August 10, 2020. https://core.ac.uk/download/pdf/17301377.pdf
71. Birdsey J, Sieber WK, Chen GX, et al. National survey of long-haul truck driver injury and health: health behaviors. J Occup Environ Med. 2015;57:210–216. 10.1097/JOM.0000000000000338 [PubMed: 25654523]
72. Thiese M, Ott U, Murtaugh M, Hegman KT. Fatigue and sleep factors related to safety critical events. Research Program Briefing. University of Utah Rocky Mountain Center for Occupational and Environmental Health; 2019. Accessed August 10, 2020. https://www.vtti.vt.edu/PDFs/fatigue-2017/monday-am/causation/Thiese.pdf
73. Apostolopoulos Y, Lemke MK, Hege A, et al. Work and chronic disease: comparison of cardiometabolic risk markers between truck drivers and the general U.S. population. J Occup Environ Med. 2016;58(11):1098–1105. doi:10.1097/JOM.0000000000000867 [PubMed: 27820759]
74. Apostolopoulos Y, Lemke MK, Sonmez S, Hege A. The obesogenic environment of commercial trucking: a worksite environmental audit and implications for systems-based interventions. Am J Health Educ. 2016;47:85–93. doi:10.1080/19325037.2015.1133339
75. AI Pack, Dinges DF, Maislin F. A study of prevalence of sleep apnea among commercial truck drivers. DOT-RT-02-030. Washington DC: Federal Motor Carrier Safety Administration; 2002. doi:10.21949/1502926
76. Berger M, Varvarigou RA, Reilly A, Czeisler CA, Maholtra A, Kales SN. Employer-mandated sleep apnea screening and diagnosis in commercial drivers. J Occup Environ Med. 2012;54(8):1017–1025. doi:10.1097/FJOM.0b013e3182572el6 [PubMed: 22850349]
77. Desmond PA, Matthews G, Bush J. Individual differences in fatigue and stress states in two field studies of driving. Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting; 2001:1571–1575. doi:10.1177/154193120104502302
78. Chandler JF, Arnold RD, Phillips JB, Turnmire AE. Predicting individual differences in response to sleep loss: application of current techniques. Aviat Space Environ Med. 2013;84(9):927–937. 10.3357/asem.3581.2013 [PubMed: 24024304]
79. Gertler J, Popkin S, Nelson D, O'Neil K. Toolboxfor transit operator fatigue. Transit Cooperative Research Program (TCRP) Report 81. Washington, DC: Transportation Research Board, National AcademyPress; 2002. Accessed August 10, 2020. https://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_81.pdf
80. Bureau of Labor Statistics. Injuries, Illnesses and Fatalities. Census of Fatal Occupational Injuries: Industry by transportation incidents and homicides; 2017. Accessed February 8, 2019. https://www.bls.gov/iif/oshcfoi1.htm
81. Blower D, Green PE. Type of motor carrier and driver history in fatal bus crashes. Transp Res Rec. 2010;2194:37–43. doi:10.3141/2194-05

82. FMCSA and NHTSA. The bus crash causation study report to Congress; 2009.
83. Hamed MM, Hensher DA, Al-Masaied HR. The duration between traffic accidents in the taxi sector: an empirical study. Road Transp Res. 1997;6(1):64–73.
84. Miyamoto M, Konno S, Gembun Y, Liu X, Minami K, Ito H. Epidemiological study of low back pain and occupational risk factors among taxi drivers. Ind Health. 2008;46(2):112–117. doi:10.2486/indhealth.46.112 [PubMed: 18413963]
85. Zhao Y, Zhang J, He X. Risk factors contributing to taxi involved crashes: a case study in Xi'an, China. Period Polytech Transp Eng. 2015;43(4):189–198. doi:10.3311/PPtr,7742
86. Meng F, Li S, Cao L, et al. Driving fatigue in professional drivers: a survey of truck and taxi drivers. Traffic Inj Prev. 2015;16(5):474–483. doi:10.1080/15389588.2014.973945 [PubMed: 25357206]
87. Wang Y, Li L, Prato CG. The relation between working conditions, aberrant driving behavior and crash propensity among taxi drivers in China. Accid Anal Prev. 2019;126:17–24. doi:10.1016/j.aap,2018.03.028 [PubMed: 29625691]
88. Kwon S, Kim H, Kim GS, Cho E. Fatigue and poor sleep are associated with driving risk among Korean occupational drivers. J Transport Health. 2019:14. doi:10.1016/j.jth.2019.100572
89. Sakai K, Takashi Y. Driving and subsidiary behavior of taxi drivers working alternate day shifts. J Human Ergo. 1975;4(2):115–127.
90. Ueda T, Hashimoto M, Yasui I, Sunaga M, Higashida T, Hara I. A questionnaire study on health of taxi drivers. Relations to work conditions and daily life. Sangyo Igaku. 1989;31(3):162–175. doi:10.1539/johl959.31.16.2 [PubMed: 2795989]
91. Dalziel JR, Job RFS. Motor vehicle accidents, fatigue and optimism bias in taxi drivers. Accid Anal Prev. 1997;29(4):489–494. doi:10.1016/S0001-4575(97)00028-6 [PubMed: 9248507]
92. Lim SM, Chia SE. The prevalence of fatigue and associated health and safety risk factors among taxi drivers in Singapore. Singapore Med J. 2015;56(2):92–97. doi:10.11622/Fsmedj.2014169 [PubMed: 25532512]
93. Susilowati IH, Nurhafizhah T, Maulana A, et al. Safety risk factors amongst online motorcycle taxi drivers who provide public transportation in Depok, Indonesia. Ind J Public Health Res Development. 2018;9(10):578–583. doi:10.5958/0976-5506.2018.01408.0
94. Menendez C, Socias-Morales C, Konda S, Ridenour M. Individual, business-related, and work environment factors associated with driving tired among taxi drivers in two metropolitan U.S. cities. J Safety Res. 2019;70:71–77. doi:10.1016/j.jsr.2019.05.001 [PubMed: 31848011]
95. Li MK, Yu JJ, Ma L, Zhang W. Modeling and mitigating fatigue-related accident risk of taxi drivers. Accid Anal Prev. 2019;123:79–87. doi:10.1016/j.aap.2018.11.001 [PubMed: 30468949]
96. Husain NA, Mohamad J, Idris MA. Daily emotional demands on traffic crashes among taxi drivers: fatigue and safety motivation as mediators. IATSS Res. 2019;43(4):268–276. doi:10.1016/j.iatssr,2019.03.001
97. Anund A, Fors C, Ihlstrom J, Kecklund G. An on-road study of sleepiness in split shifts among city bus drivers. Accid Anal Prev. 2018;114:71–76. doi:10.1016/j.aap.2017.05.005 [PubMed: 28506403]
98. Ilhstrom J, Kecklund G, Anund A. Split-shift work in relation to stress, health and psychosocial work factors among bus drivers. Work. 2017;56(4):531–538. doi:10.3233/WOR-172520 [PubMed: 28372339]
99. Lee S, Kim H, Byun J, Jang T. Sleepiness while driving and shiftwork patterns among Korean bus drivers. Ann Occup Environ Med. 2017;29(1):48. doi:10.1186/s40557-017-0203-y [PubMed: 29043087]
100. Kim H, Jang T, Kim H, Lee S. Evaluation of fatigue and accident risk of Korean commercial bus drivers. Tohoku J Exp Med. 2018;246(3):191–197. doi:10.1620/tjem.246.191 [PubMed: 30487372]
101. Besharati MM, Tavakoli KA. Factors contributing to intercity commercial bus drivers' crash involvement risk. Arch Environ Occup Health. 2018;73(4):243–250. doi:10.1080/19338244.2017.1306478 [PubMed: 28318430]

102. Chu HC. Assessing factors causing severe injuries in crashes of high-deck buses in long-distance driving on freeways. Accid Anal Prev. 2014;62:130–136. doi:10.1016/j.aap.2013.09.016 [PubMed: 24144498]

103. Santos JA, Lu JL. Occupational safety conditions of bus drivers in Metro Manila, the Philippines. Int J Occup Safety Erg. 2016;22(4):508–513. doi:10.1080/10803548.2016.1151700

104. Hui DSC, Chan JKW, Ko FWS, et al. Prevalence of snoring and sleep-disordered breathing in a group of commercial bus drivers in Hong Kong. Int Med J. 2002;32(4):149–157. doi:10.1046/j,1444-0903.2001.00196.x

105. Hui DS, Ko FWS, Chan JKW. Sleep-disordered breathing and continuous positive airway pressure compliance in a group of commercial bus drivers in Hong Kong. Respirology. 2006;11(6):723–730. doi:10.1111/j.1440-1843.2006.00932.x [PubMed: 17052300]

106. Bowler N, Gibson H. Fatigue and Its Contribution to Railway Incidents. Rail Safety and Standards Board (RSSB) Special Topic Report; 2015. Accessed September 15, 2020. https://www.rssb.co.uk/what-we-do/key-industry-topics/fatigue-and-alertness/fatigue-and-its-contribution-to-railway-incidents

107. Hursh SR, Raslear TG, Kaye S, Fanzone JF. Validation and calibration of a fatigue assessment tool for railroad work schedules, summary report. DOT/FRA/ORD-06/21. Washington, DC: Federal Railroad Administration; 2006. Accessed August 10, 2020. https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/17499/ord0621.pdf

108. Gertler J, Nash D. Optimizing staffing levels and schedules for railroad dispatching centers. Federal Railroad Administration; 2004. https://pdfs.semanticscholar.org/f748/3a0942b8f42e3fb59cd10f79ca308ea76e31.pdf

109. Gertler J, DiFiore A, Raslear T. Fatigue status of the U.S. railroad industry. Final Report. DOT/FRA/ORD-13/06; 2013. Accessed August 10, 2020. https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/2929/TR_Fatigue_Status_US_Railroad_Industry_CO_20121119_20130221_FINAL.pdf

110. Sherry P. Managing fatigue in the railroad industry. Denver, CO: University of Denver National Center for Intermodal Transportation, Intermodal Transportation Institute; 2007.

111. Allen P, Wadsworth E, Smith A. Seafarers' fatigue: a review of the recent literature. Int Marit Health. 2008;59(1-4):81–92. [PubMed: 19227741]

112. Miller NL, Matsangas P, Kenney A. The role of sleep in the military: implications for training and operational effectiveness. In: Laurence JH, Matthews MD, eds. The Oxford Handbook of Military Psychology. Oxford University Press; 2012:262–281.

113. Reid KJ, Turek FW, Zee PC. Enhancing sleep efficiency on vessels in the tug/towboat/barge industry Transportation Research Board: Washington, DC. National Cooperative Freight Research Program NCFRP Report 36; 2016. doi:10.17226/21933

114. Comperatore CA, Rivera PK. Crew endurance management practices: a guide for maritime operations. US Coast Guard Technical Report Washington, DC: U.S. Coast Guard; 2003. Accessed February 13, 2021. https://apps.dtic.mil/dtic/tr/fulltext/u2/a413881.pdf

115. MacLachlan M. Maritime Psychology Research in Organizational & Health Behavior at Sea. Springer International Publishing; 2017. https://link.springer.com/content/pdf/10.1007%2F978-3-319-45430-6.pdf

116. Oldenburg M, Jensen HJ, Latza U, Baur X. Seafaring stressors aboard merchant and passenger ships. Int J Public Health. 2009;54:96–105. doi:10.1007/s00038-009-7067-z [PubMed: 19288290]

117. Bjerner B, Holm A, Swensson A. Diurnal variation in mental performance: a study of three-shift workers. Br J Ind Med. 1955;12(2):103–110. doi:10.1136/Foem,12.2.103 [PubMed: 14363590]

118. Rosa RR, Bonnet MH. Performance and alertness on 8 h and 12 h rotating shifts at a natural gas utility. Ergonomics. 1993;36(10):1177–1193. doi:10.1080/0140139308967987 [PubMed: 8223409]

119. Rosa RR. Extended workshifts and excessive fatigue. J Sleep Res. 1995;4(suppl 2):51–56. doi:10.1111/j,1365-2869.1995.tb00227.x [PubMed: 10607212]

120. National Safety Council. Fatigue in safety critical industries–impacts, risks & recommendations; 2018. Accessed August 10, 2020. http://safety.nsc.org/fatigue-in-safety-critical-industries-report

121. Techera U, Hallowell M, Littlejohn R. Worker fatigue in electrical transmission and distribution line construction. J Const Eng Manage. 2019;145(1):04018119. doi:10.1061/(ASCE)C0.1943-7862.0001580
122. Baker TL, Campbell SC, Linder KD, Moore-Ede MC. Control-room operator alertness and performanceinn nuclear power plants. Report No. EPRI-NP-6748. Washington, DC: Environmental Protection Agency; 1990. Accessed September 3, 2020. https://inis.iaea.org/search/search.aspx?orig_q=RN:21050053
123. Baker K, Olson J, Morisseau D, Persensky J. Overtime and shift scheduling: an examination of their relationship with nuclear power plant safety performance. (NUREG/CR-5921). Washington, DC: U.S. Nuclear Regulatory Commission; 1994. Accessed September 3, 2020. doi:10.1177/001872089403600206
124. Nuclear Regulatory Commission. Regulatory guide for implementing fatigue management programs. Accessed September 3, 2020. https://www.nrc.gov//reactors/operating/ops-experience/fitness-for-duty-programs/reg-guide-ifmp.html
125. Nuclear Energy Institute. Managing personnel fatigue at nuclear power reactor sites. Report NE1-0611; 2008. Accessed February 28, 2021. https://www.nrc.gov/docs/M0903/ML090360158.pdf
126. Nuclear Regulatory Commission. Regulatory guide 5.75 for fatigue management for nuclear power plant personnel; 2009. Accessed February 28, 2021. https://www.nrc.govdocs/ML084/ML083450028.pdf
127. Gander P, Hartley Lowell D, Cabon P. Hitchcock E, Mills A, Popkin S. Fatigue risk management: organizational factors at the regulatory and industry/company level. Accid Anal Prev. 2011;43:573–590. doi:10.1016/j.aap.2009.11.007 [PubMed: 21130218]
128. Sprajcer M, Thomas MJW, Sargent C, et al. How effective are Fatigue Risk Management Systems (FRMS)? A review. Accid Anal Prev. 2022:165:106398. doi:10.1016/j.aap.2021.106398 [PubMed: 34756484]
129. Kudo T, Belzer MH. The association between truck driving compensation and safety performance. Saf Sci. 2019;120:447–455. doi:10.1016/j.ssci.2019.07.026
130. Christie N, Ward H. The health and safety risks for people who drive for work in the gig economy. J Transport Health. 2019;13:115–127. doi:10.1016/j.jth.2019.02.007
131. Crain TL, Brossoit RM, Robles-Saenz F, Tran M. Fighting fatigue: a conceptual model of driver sleep in the gig economy. Sleep Health. 2020;6(3):358–365l. doi:10.1016/j.sleh.2020.02.004 [PubMed: 32205095]
132. Wang X, Xu C. Driver drowsiness detection based on non-intrusive metrics considering individual specifics individual specifics. Accid Anal Prev. 2015;95:350–357. doi:10.1016/j.aap.2015.09.002 [PubMed: 26433567]
133. Masala GL, Grosso E. Real time detection of driver attention: emerging solutions based on robust iconic classifiers and dictionary of poses. Transp Res Part C: Emerg Technol. 2014;49:32–42. doi:10.1016/j.trc.2014.10.005
134. Sparrow AR, LaJambe CM, Van Dongen HPA. Drowsiness measures for commercial motor vehicle operations. Accid Anal Prev. 2019;126:146–159. doi:10.1016/j.aap.2018.04.020 [PubMed: 29704947]
135. Federal Motor Carrier Safety Administration (FMCSA). Request for Information Concerning Large Truck Crash Causal Factors. Study Notice by the Federal Motor Carrier Safety Administration on 01/15/2020. Accessed on May 6, 2020. https://www.federalregister.gov/documents/2020/01/15/2020-00557/request-for-information-concerning-large-truck-crash-causal-factors-study
136. Dickers J. Industry launches fatigue risk management guidelines. Utility Magazine, February 8; 2016. Accessed September 5, 2020. https://utilitymagazine.com.au/industry-launches-fatigue-risk-management-guidelines/
137. Electric Power Research Institute. Fatigue management in the electric utility industry: characterization and mitigation approaches. Accessed September 6 2020. https://www.epri.com/research/programs/014875/results/3002016547

138. Avers KB, Johnson WB, Banks JO, Nei D, Hensley E. Fatigue solutions for maintenance: from science to workplace reality. Report No.DOT/FAA/AM-11/19. Washington, DC: Federal Aviation Administration; 2011. Accessed August 10, 2020. http://libraryonline.erau.edu/online-full-text/faa-aviation-medicine-reports/AM11-19.pdf

139. International Air Transport Association (IATA). Safety report 2015. Montreal, Quebec: International Air Transport Association; 2016. Accessed August 10, 2020. https://skybrary.aero/bookshelf/books/3408.pdf

140. Federal Aviation Administration (FAA). Fatigue risk management systems for aviation safety. Advisory Circular No. 120-103A; 2013. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

141. American Public Transportation Association. Fatigue management program requirements; 2017. Accessed August 11, 2020. https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-RT-OP-S-023-17.pdf

142. North American Fatigue Management Program (NAFMP). U.S. DOT-Federal Motor Carrier Safety Administration; 2020. Accessed July 20, 2020. https://www.fmcsa.dot.gov/research-and-analysis/research/north-american-fatigue-management-program

143. Lerman SE, Eskin E, Flower DJ, et al. Fatigue risk management in the workplace. J Occup Environ Med. 2012;54(2):231–258. doi:10.1097/JOM.0b013e318247a3b0 [PubMed: 22269988]

144. Satterfield BC, Van Dongen HPA. Occupational fatigue, underlying sleep and circadian mechanisms, and approaches to fatigue risk management. Fatigue: Biomed Health Behav. 2013;1(3):118–136. doi:10.1080/21641846.2013.798923