Transportation Research Part F 76 (2021) 297–308

Contents lists available at ScienceDirect

Transportation Research Part F

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

Hours-of-service compliance and safety outcomes among long-haul truck drivers

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ARTICLE INFO

Article history:
Received 23 March 2020
Received in revised form 28 October 2020
Accepted 29 November 2020
Available online 28 December 2020

Keywords:
Long-haul truck drivers
Occupational safety
Motor vehicle crashes
Hours-of-service
Public policy compliance
Public policy epidemiology

ABSTRACT

Introduction: U.S. long-haul truck drivers (LHTD) experience the most work-related fatalities of any occupation. Hours-of-service (HOS) regulations constitute key public policies aimed at improving safety outcomes; however, little is known about the factors that are associated with HOS compliance, and questions remain about the efficacy of HOS laws in improving safety. This study seeks to identify factors associated with HOS compliance and to determine the significance of HOS compliance in sleep-related safety risk.

Materials and methods: Using cross-sectional survey data from 260 U.S. LHTD that measured demographic, work organization, sleep health, hours-of-service compliance, and sleep-related safety performance characteristics, we: 1) compiled descriptive statistics to summarize the variables included in this study; 2) performed bivariate correlation analyses between an HOS composite variable called "Hours-of-Service Violations" and the demographic, work organization, and sleep health variables; 3) conducted an ordinal logistic regression analysis, using the HOS composite variable as the outcome variable; and 4) conducted a multinomial logistic regression analysis, using a sleep-related safety performance composite variable called "Sleep-Related Safety Risk" as the outcome variable.

Results: Higher scores on the HOS composite variable were significantly associated with more miles driven per week, longer daily work hours, a higher frequency of a fast pace of work, shorter sleep duration, and poorer sleep quality. Statistically significant predictor variables in the Hours-of-Service Violations composite variable model were driving less than 2,500 miles per week (OR = 0.53), working less than 11 h daily (OR = 0.19) or between 11 and 13 h daily (OR = 0.43); a lower frequency of fast pace of work (OR = 0.42); and work-night sleep duration (OR = 0.80). Fewer than 11 h of work daily (OR = 0.37), a higher perception of supervisor support (OR = 0.17), and ever having told supervisor about being too tired to drive (OR = 0.42) were significant predictors in the Sleep-Related Safety Risk composite variable model, while the hours-of-service compliance variables were not.

Conclusions: Reducing daily work hours and pace of work, strengthening driver-supervisor relationships and improving supervisor leadership and risk management techniques, making driver compensation fairer, and revisiting HOS policies may represent high-leverage targets for improving regulatory compliance and safety outcomes.

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https://doi.org/10.1016/j.trf.2020.11.017
1369-8478/

1. Introduction

The trucking industry plays a vital role in the United States economy, moving over 11 billion tons of freight and generating nearly $800 billion in gross freight revenues annually (Costello, 2019). To accommodate this need, the approximately 900,000 for-hire carriers, 772,000 private carriers, and 85,000 'other' interstate motor carriers in the U.S. operate 3.68 million Class 8 trucks, including tractor-trailers and straight trucks, which constitute 13.4% of all registered vehicles in the nation and traveled an estimated 181.5 billion miles in 2017 (Costello, 2019). Nearly 8 million people are employed in jobs related to trucking activity, with 880,710 of these individuals employed as heavy and tractor-trailer truck drivers (i.e., long-haul truck drivers [LHTD]) (Bureau of Labor Statistics, 2018a; Costello, 2019).

Long-haul truck drivers transport freight from one location to another, typically across long distances (Bureau of Labor Statistics, 2018b). Freight assignments are typically given by a dispatcher or supervisor, who also function as intermediaries between drivers and customers. In addition to driving, LHTD may have a number of other job tasks, including: equipment inspection and maintenance; cargo securement, loading, and unloading; paperwork completion and submission; and routing and scheduling decisions (Bureau of Labor Statistics, 2018b). The precise work organization of any given LHTD depends on what type of driver they are, what routes they are on, and the type of freight their company hauls (Apostolopoulos, Lemke, & Sonmez, 2014). Further, LHTD can also vary in their time at home; for many LHTD, they are away from home for weeks or months at a time, and thus their worksites represent 'home' for prolonged periods (Apostolopoulos et al., 2014; Bureau of Labor Statistics, 2018b).

Long-haul truck drivers experience multiple physical and psychological strains endemic to their profession that impact their health and safety (Apostolopoulos et al., 2014; Belzer, 2009). Because of the high-risk nature of operating a heavy and tractor-trailer due to the potential for traffic accidents, these drivers experience the most work-related fatalities of any occupation; further, the number of these trucks involved in fatal, injury, and property damage crashes have all risen in recent years (Bureau of Labor Statistics, 2018b; Federal Motor Carrier Safety Administration, 2019b; U.S. Bureau of Labor Statistics, 2019). These disproportionately poor safety outcomes have far-reaching repercussions for the drivers themselves, as well as other roadway users, consumers, trucking companies, insurance companies, and the broader U.S. economy (Apostolopoulos et al., 2014).

The U.S. Department of Transportation (USDOT) has most of the jurisdiction in driver health and safety issues (Apostolopoulos et al., 2014). The Federal Motor Carrier Safety Administration (FMCSA), an agency within the USDOT, regulates the trucking industry and provides safety oversight (Federal Motor Carrier Safety Administration, 2018b). As part of its regulatory functions, FMCSA issues hours-of-service (HOS) regulations as a means to reduce driver sleepiness (Federal Motor Carrier Safety Administration, 2019a). In brief, HOS regulations stipulate that drivers: a) may not drive more than 11 h after 10 consecutive hours off-duty ("11-hour rule"); b) may not drive beyond the 14th consecutive hour on-duty after 10 consecutive hours off-duty ("14-hour rule"); c) may not drive after 70 h on-duty in 8 consecutive days ("70-hour rule"), but may restart this period after taking 34 or more consecutive hours off-duty ("34-hour restart"); and d) must take at least 8 consecutive hours in the sleeper berth, plus a separate 2 consecutive hours either in the sleeper berth, off-duty, or a combination of the two ("10-hour rest breaks") (Federal Motor Carrier Safety Administration, 2013). Similar laws exist in other countries as well, although they typically vary from those in the United States. For example, driving time rules in the European Union are more restrictive than those in the United States, particularly with regard to daily and weekly driving time (Department of Mobility and Transport, 2020), while Australia stipulates work and rest times in a more nuanced fashion and provides avenues for exemptions to these mandates (National Heavy Vehicle Regulator, 2020).

Hours-of-service regulations continue to engender controversy among industry stakeholders and policymakers. Among trucking companies and drivers themselves, reaction to HOS regulations has been mixed, with favorable reaction to some rules (e.g., 34-hour restart) and dislike of others (e.g., 14-hour rule) (Dick, Hendrix, & Knipling, 2006). Others have questioned the utility of a "one-size-fits-all" approach in the context of the unique demands of long-haul trucking and have posited that these rules may result in unintended consequences that exacerbate safety outcomes (Anderson, Ogden, Cunningham, & Schubert-Kabban, 2017). Another critical concern is the degree of driver compliance to HOS regulations, as the effectiveness of these laws is contingent on drivers actually obeying them, and those drivers who do not agree with regulations or have sufficient time pressures or economic incentives may not comply with them (Beilock, 2003; Olson, 2006). For example, time pressures caused by tight pickup or delivery deadlines that are often outside the driver's control, and financial pressures that are exacerbated by pay structures that do not adequately compensate drivers for their work, such as pay by-the-mile, no overtime pay, and inadequate detention time pay, may lead drivers to find ways to circumvent these laws (Beilock, 2003; Belman & Monaco, 2001; Farrell, Soccolich, & Hanowski, 2016; Olson, 2006).

Despite the critical bearing that HOS regulations have on the trucking industry, little is known about those factors that are associated with driver compliance with these laws. Further, there remain many questions about the efficacy of HOS regulations in improving safety outcomes, especially in the context of the broader occupational milieu of long-haul trucking. Together, a better understanding of driver compliance with HOS regulations and new insights into the effectiveness of these laws for improving LHTD safety outcomes could lead to better HOS policy design, refinement, implementation, and enforcement that could maximize the impacts of these well-intentioned public policies. Thus, the current study has two objectives: 1) to identify the demographic, work organization, and sleep health factors that are associated with drivers' HOS compliance; and 2) to determine the significance of HOS compliance, in conjunction with other relevant demographic, work organization, and sleep health factors, in sleep-related safety risk.

2. Materials and methods

2.1. Study setting and data collection

Using a cross-sectional observational study design and the use of an interviewer-administered survey, the Trucker Sleep Disorders Survey (TSLDS), data were collected from 262 U.S. LHTD at a large truck stop in central North Carolina. Drivers were recruited at the truck stop by field researchers; researchers circulated around the truck stop and asked drivers for their participation in the study. Researchers informed drivers what the study entailed, the purposes of the study, how much time it would require, and information about consent. The survey was interviewer-administered to allow for interpretation of questions and in order to address any reading literacy issues. Inclusion criteria stated that only male drivers who self-identified as a long-haul driver (i.e., meaning the driver spends multiple nights a week away from home) and were 21 years of age or older (the eligibility for being a U.S. long haul trucker) were eligible for the study. This meant that drivers were excluded if they were regional-based or did not spend nights away from home. The survey data were collected over a six-month time period between October of 2012 and March of 2013, and each interviewer-administered survey took between 45 and 60 min to complete. As a result of participating, drivers were given $15 in cash. Further details of the methods of this study are provided in previous published articles (Hege, Apostolopoulos, Perko, Sönmez, & Strack, 2016; Hege et al., 2015; Lemke, Apostolopoulos, Hege, Sönmez, & Wideman, 2016; Lemke, Hege, Perko, Sönmez, & Apostolopoulos, 2015). This study was approved by the Institutional Review Board (IRB) at the University of North Carolina-Greensboro (12–0248).

For this study, the TSLDS was developed by making use of other key established surveys focused on work, sleep, and health, as well as from our previous work with truck drivers (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989; National Sleep Foundation, 2012; Netzer, Stoohs, Clark, & Strohl, 1999; Philip & Åkerstedt, 2006). To validate the survey, public health professionals reviewed it and provided feedback, and the survey was revised based on this feedback; after that, the survey was pilot tested with six long-haul truck drivers to check for any potential issues, provide additional opportunities for revisions, determine construct validity, identify missing items, clarify scale distributions, conduct item correlations, and determine reliability.

The TSLDS has five primary components: sleep health, sleep impacts, work organization, cardiometabolic health, and demographics. For this study, we focused on the following components and variables: demographics (age, race/ethnicity, education, income); work organization (driver type, driving experience, compensation type, union membership, miles per week, days on road per month, work hours per day, daily schedule regularity, hours of day regularity, days working per week regularity, pace of work, supervisor support, telling a supervisor not alert enough to perform job safely, and perception of delivery schedule); sleep health (worknight sleep duration, worknight sleep quality); hours of service violations (14-hour rule, 70-hour rule, 10-hour rest break rule, underreporting work hours in logbook); and sleep-related safety performance (falling asleep while working, driving their truck while sleepy, sleepiness impacting their job performance, sleepiness impacting their concentration, made a serious error due to sleep, caused an accident due to sleep, been in an accident due to sleep, had a near miss due to sleep). Due to missing data from two of the LHTD participants, the final sample size used for statistical analyses was 260.

2.2. Study measures

2.2.1. Demographics

For demographics, drivers were asked about their age (in years) in a continuous fashion, while race/ethnicity, educational attainment, and income – specifically, the driver's personal income after taxes from the previous year – were asked categorically. For analytical purposes, and based on the distribution of responses, driver answers to the age, race/ethnicity, education, and income questions were re-coded into the following categories: 18–39 years old, 40–49 years old, 50–59 years old, or 60 years old and older; White/Caucasian, Black/African American, Latino/Hispanic, or Multiracial/Other; high school or less, some college, or college or higher; and $40,000 or less, between $40,000 and $60,000, and $60,000 or greater, respectively.

2.2.2. Work organization

Drivers were asked in a Boolean fashion if they were a member of a labor-related union, if they have ever told their supervisor they were too tired to drive, and if they worked the same schedule every day, the same number of hours every day, and the same days each week. Drivers were also asked how long they have been driving a truck for (in years) and how many miles they drive on average per week. They were further asked about how they were paid (by-the-mile, by-the-load, or other); the number of hours on average that they work a day, including driving and other work-related tasks (in one-hour increments); and the number of days per month that they are on the road (less than 5 days, 6–10 days, 11–15 days, 16–20 days, 21–25 days, and 26–30 days; these selections were re-categorized based on the distribution of responses and for analytical purposes as 20 days or less, 21–25 days, or 26 or more days). Finally, drivers were asked how often their jobs demanded they worked at a very fast pace, how often the time they are allowed by their dispatcher/shipper to deliver a load was realistic, and how often they had a good working relationship with their supervisors. The response selections for this set of questions were: never, rarely, sometimes, often, or always; however, for analytical purposes, and based on the distribution of responses, these selections were re-categorized as either "sometimes or less" or "often or always".

2.2.3. Sleep health

To measure sleep duration, participants were asked how many hours they usually sleep on workdays. For sleep quality, drivers were asked often they obtain a good night's sleep on workdays within the previous two weeks. For these questions, response selections included: "never", "rarely", almost every night", and "every night". For analytical purposes, and based on the distribution of responses, these selections were recategorized as either "never or rarely a good night" or "almost always or always a good night."

2.2.4. Hours-of-Service violations

Drivers were asked a series of questions related to the frequency of violating several key federal hours-of-service regulations (Federal Motor Carrier Safety Administration, 2013). In particular, they were asked how often exceeded the "14-hour rule" (driving after 14 consecutive hours on-duty), the "70-hour rule" (exceeding 70 h on-duty time in any 8-day period), and the "10-hour rule" (failing to take a full 10 consecutive hours off-duty, with at least 8 consecutive hours of sleeper berth [i.e., sleeping] time), as well as how often they underreported their work hours in their logbooks. The response selections for these questions included: never, rarely, sometimes, often, or always. For analytical purposes, and based on the distribution of responses, these selections were re-categorized as either "never or rarely" or "at least sometimes".

2.2.5. Sleep-related safety risk

For sleep-related safety risk, drivers were asked two sets of questions. First, they were asked to report their frequency of falling asleep while working, driving their truck while sleepy, having sleepiness impact their job performance, and having sleepiness impact their concentration during the past month. For each of these four questions, the response selections included: never; one time; two or three times; four or five times; more than five times. Based on the distribution of the responses, and for analytical purposes, we re-categorized these as either "never" or "one or more times". Second, they asked to report in a Boolean fashion if they had ever, due to sleep, made a serious error, caused an accident, been in an accident, or had a near miss.

2.3. Data analysis

First, descriptive statistics (frequencies/percentages or means/standard deviations) were run to provide the overall magnitude of variables in this study. Next, we conducted bivariate Spearman correlation analyses, used for ordinal variables, between the demographic, work organization, and sleep health variables and the hours-of-service violations, and we used those findings to determine the predictor variables for subsequent regression analyses. However, prior to conducting the bivariate correlation analyses, we examined the four hours-of-service violations variables for reliability scaling; because we found a Cronbach's Alpha of 0.86 between these variables, we created a composite variable called "Hours-of-Service Violations". Composite variable scores could range from 0 to 16, based on drivers' responses on the four hours-of-service questions (never = 0, rarely = 1, sometimes = 2, often = 3, and always = 4). With the bivariate correlation analyses, we considered anything with at least $r = 0.10$ to be relevant for further regression analysis purposes; all those under 0.10 were removed.

We then conducted ordinal logistic regression analysis using the following predictor variables: worknight sleep duration; compensation type; frequency of fast pace of work; frequency of supervisor support; telling a supervisor too tired to drive; worknight sleep quality; and miles driven per week (categorically). For the ordinal logistic regression analysis, we grouped the Hours-of-Service Violations composite variable based on the distribution of driver responses as follows: 0–1 = "none to very rarely"; 2–4 = "rarely"; 5–8 = "sometimes"; and 9 or more = "frequently or always". With the ordinal logistic regression, we conducted a test of parallel lines to assess whether the model violated this assumption, and we obtained a nonsignificant result ($\chi = 18.995$, $p = 0.646$). Thus, we did not reject the null hypothesis and instead concluded that the assumption holds and, therefore, the model was appropriate. The proportional odds assumption appears to have held as well due to the statistical nonsignificance of our Chi-Square statistic ($p = 0.646$). We also ran bivariate logistic regression models with each of the individual HOS compliance variables as dependent outcome variables. The results of these models are found in Supplemental Tables 1-4.

Finally, we tested an ordinal logistic regression to examine the predictive power of the individual hours-of-service variables, as well as the demographic, work organization, and sleep health variables used in the ordinal logistic regression analysis, in determining sleep-related safety risk. Prior to doing so, we examined the reliability scaling of the eight sleep-related safety risk outcome variables and found a Cronbach's Alpha of 0.76 between the variables, and thus created a composite variable called "Sleep-Related Safety Risk". Composite variable scores could range from 0 to 8, based on their responses to the first set (never = 0; one or more times = 1) and second set (no = 0; yes = 1) of sleep-related safety risk questions. However, for the purposes of the logistic regression analysis, we re-categorized the variable in the following fashion: "no sleep-related safety risk outcomes"; "1 sleep-related safety risk outcome"; or "2 or more sleep-related safety risk outcomes". However, when we conducted the ordinal logistic regression model, our test of parallel lines was statistically significant ($\chi = 30.97$, $p = 0.01$). Thus, we rejected the null hypothesis and concluded that the parallel lines assumption does not hold and, therefore, the model was not appropriate. Further, the proportional odds assumption did not hold because the significance of our

Chi-Square statistic is 0.01 or < 0.05. Due to these failed assumptions, we instead ran a multinomial logistic regression, which is a less restrictive model. When running the multinomial logistic regression, we found the goodness-of-fit results to be not significant, which suggests that the model is a good fit. We also ran bivariate logistic regression models with each of the eight sleep-associated safety risk factors as dependent outcome variables, and only two of these models were statistically significant (‘‘driving truck while sleepy" and ‘‘had a near miss"). The results of these analyses are provided in Supplemental Tables 5 and 6. All of the statistical analyses were performed using SPSS 26.0 (IBM, 2018).

3. Results

3.1. Descriptive statistics

The mean driver age was 46.63 years and just over one-half (57.3%) were White/Caucasian. More than half (55.3%) of drivers had an education of high school or less and most (74.8) had a yearly income of less than $60,000. Approximately two-thirds (66.5%) of drivers were a working for hire or for a company, and most had been driving for more than five years (73.8%). Almost three-fourths (70.4%) of drivers were compensated by-the mile. The average miles driven per week was 2,812.61, and over two-thirds of drivers (70.5%) worked 11 or more hours per day; further, shift work scheduling was common, as most reported working a varying schedule, both daily and weekly. Approximately half of drivers were often or always facing a fast pace of work, and 35.4% also felt their delivery schedule was only sometimes or less ‘‘realistic". Almost one in four drivers (23.7%) perceived their supervisor as sometimes or less providing them support, and almost forty percent (37.7%) had told a supervisor they were too tired to drive. The mean driver sleep duration was 6.95 h; however, nearly half (45.9%) reported obtaining less than seven hours daily, and 38.2% felt like they never or rarely got a good night's sleep. Regarding hours-of-service violations, more than one-fourth of drivers reported at least sometimes having done so, and the breakdown of the Hours-of-Service Violations composite variable scores was as follows: 0–1 (30.6%); 2–4 (26.7%); 5–8 (16.3%); and 9–16 (26.4%). Finally, regarding sleep-related safety risks, 54.9% of drivers had driven sleepy, one in five (21.2%) had been in an accident due to sleep, and more than one half (52.1%) reported having a near-miss due to sleep; further, the breakdown of the Sleep-Related Safety Risk composite variable scores was as follows: 0 (39.6%); 1 (22.0%); and 2 or more (38.4%). The findings from the descriptive statistical analyses can be found in Table 1.

3.2. Bivariate correlation analyses

The bivariate correlation analyses between the demographic, work organization, and sleep health variables and the Hours-of-Service Violations composite variable revealed several statistically significant associations. Higher scores on the HOS composite variable were significantly associated with more miles driven per week, longer daily work hours, a higher frequency of a fast pace of work, shorter sleep duration, and poorer sleep quality. While not statistically significant, greater supervisor support was associated with lower scores on the Hours-of-Service Violations composite variable; in contrast, being paid by-the-mile, as well as reporting having told supervisors about being too tired to drive, were associated (although also not significantly) with higher scores on the composite variable. We, therefore, considered those variables relevant for regression analyses. Table 2 provides the complete findings from the bivariate correlation analyses.

3.3. Ordinal logistic regression (hours-of-service violations as outcome variable)

With the Hours-of-Service Violations composite variable as the outcome variable, the ordinal logistic regression model was statistically significant (χ = 80.86, $p < 0.01$). Statistically significant predictor variables in this model were driving less than 2,500 miles per week (OR = 0.53); working less than 11 h daily (OR = 0.19) or between 11 and 13 h daily (OR = 0.43); a lower frequency of fast pace of work (OR = 0.42); and worknight sleep duration (OR = 0.80). Alternately, these findings can be interpreted as meaning that drivers who travel less than 2,500 miles per week are 47% less likely, work between 11 and 13 h daily are 57% less likely, work less than 11 h daily are 81% less likely, experience a lower frequency of a fast pace of work are 58% less likely, and experience a shorter sleep duration (expressed in hours) were 20% less likely, of having a higher score on the HOS composite variable. Table 3 provides the complete findings for this ordinal logistic regression analysis.

3.4. Multinomial logistic regression (sleep-related safety risk as outcome variable)

With the Sleep-Related Safety Risk composite variable as the outcome variable, the multinomial logistic regression model was statistically significant (χ = 52.45, $p < 0.01$). Using zero safety risk outcomes as the reference category, with one safety risk outcome, the only statistically significant predictor was working less than 11 h daily when compared to working 13 or more hours daily (OR = 0.37). However, with two safety risk outcomes in comparison to zero safety risk outcomes, the results showed that increased supervisor support (OR = 0.17) and a driver having told a supervisor that they were too tired to drive (OR = 0.42) were significant predictors. Further, and although not statistically significant, each hour of longer sleep duration led to decreased odds of having two or more safety risk outcomes (OR = 0.80). Table 4 provides the complete findings for this multinomial logistic regression analysis.

Table 1
Demographics, work organization, sleep health, hours-of-service violations, and safety performance.

Variable	N (%)	Variable	N (%)
Demographics		**Sleep Health**	
Age (years)	46.63 (1.62)*	Worknight Sleep Duration (hours)	6.95 (1.62)*
18–39	69 (26.6)	*Less than 6*	49 (18.9)
40–49	73 (28.2)	*6–7*	70 (27.0)
50–59	91 (35.1)	*7–9*	117 (45.2)
60+	26 (10.0)	*More than 9*	23 (8.9)
Race/Ethnicity		Never or Rarely Good Worknight Sleep Quality	98 (38.2)
White/Caucasian	149 (57.3)	**Hours-of-Service Violations**	
Black/African American	84 (32.3)	At Least Sometimes 14-Hour Rule	114 (43.8)
Latino/Hispanic	22 (8.5)	At Least Sometimes 70-Hour Rule	70 (27.0)
Multiracial/Other	5 (1.9)	At Least Sometimes 10-Hour Rest Breaks	107 (41.3)
Education		At Least Sometimes Underreporting in Logbook	96 (37.1)
High school or less	143 (55.3)	Composite Variable Scores	
Some college	79 (30.5)	*0–1*	80 (30.6)
College or higher	37 (14.2)	*2–4*	69 (26.7)
Annual Income		*5–8*	42 (16.3)
$40,000 or less	93 (36.0)	*9–16*	69 (26.4)
$40,000 - $60,000	100 (38.8)	**Sleep-Related Safety Risks**	
$60,000 or greater	65 (25.2)	Falling Asleep While Working	94 (36.3)
Work Organization		Driving Truck While Sleepy	140 (54.9)
Driver Type		Sleepiness Impact Performance	114 (43.8)
Company driver	107 (42.1)	Sleepiness Impact Concentration	99 (38.4)
For hire	62 (24.4)	Made Serious Error Due to Sleep	83 (32.0)
Owner operator	85 (33.5)	Caused an Accident Due to Sleep	18 (6.9)
Driving Experience (years)	14.97 (11.53)*	Been in an Accident Due to Sleep	55 (21.2)
5 or less	68 (26.2)	Had a Near-Miss Due to Sleep	135 (52.1)
Between 5 and 10	45 (17.3)	Composite Variable Scores	
More than 10	147 (56.5)	*0*	103 (39.6)
Compensation Type		*1*	57 (22.0)
By-the-mile	183 (70.4)	*2 or more*	100 (38.4)
By-the-load	34 (13.1)		
Other	43 (16.5)		
Union Membership	9 (3.5)		
Miles Per Week	2,812.61 (810.11)*		
Less than 2,500	66 (25.4)		
2,500–2,999	95 (36.5)		
3,000 or more	99 (38.1)		
Days on Road Per Month			
20 or less	40 (15.4)		
21–25	110 (42.3)		
26 or more	110 (42.3)		
Work Hours Per Day			
Less than 11	76 (29.5)		
11–13	83 (32.2)		
More than 13	99 (38.3)		
Different Daily Schedule	215 (82.7)		
Different Weekly Schedule	166 (63.8)		
Different Hours Each Day	215 (82.7)		
Often or Always Fast Pace of Work	120 (46.4)		
Sometimes or Less Realistic Delivery Schedule	90 (35.4)		
Sometimes or Less Supervisor Support	59 (23.7)		
Ever Told Supervisor Too Tired to Drive	97 (37.7)		

* Mean (SD)

4. Discussion

Long-haul truck drivers experience excessive workplace injury disparities compared to other occupations, and HOS regulations constitute key public policies aimed at improving safety outcomes. Although HOS policies have been in place in some form since 1937, numerous gaps in the literature remain pertaining to their efficacy in reducing workplace injuries (Heaton, 2005). This study sheds light on two crucial gaps: driver compliance with HOS regulations, and sleep-related safety risks due to violating HOS regulations. Overall, these findings suggest that various work organization and sleep health factors may induce HOS violations; however, it does not appear that HOS violations per se are as important as other factors for shaping sleep-related safety risk, and that the frequency of violations may actually mitigate such risks. Further, it appears that reducing pace of work, improving driver-supervisor relationships and supervisor leadership and management styles, shifting

Table 2
Associations between demographic, work organization, and sleep health variables with hours-of-service violations (bivariate correlations).

	Hours-of-Service Violations
Demographics	
Age	−0.06
Race/Ethnicity	0.00
Education	0.09
Income	0.07
Work Organization	
Driver Type	0.08
Driving Experience	−0.05
Compensation Type	0.11
Union Membership	0.04
Miles Per Week	0.21**
Days on Road Per Month	−0.01
Work Hours Per Day	0.42**
Daily Schedule	−0.05
Hours of Day	−0.05
Days Working Per Week	−0.07
Fast Pace of Work	0.32**
Supervisor Support	−0.12
Told Supervisor Too Tired	0.12
Sleep Health	
Worknight Sleep Duration	−0.31**
Worknight Sleep Quality	−0.25**

**p < 0.01; *p < 0.05

Table 3
Ordinal logistic regression model for Hours-of-Service Violations.

Hours-of-Service Violations	**OR**	***95% CI***
Compensation type (reference: other)		
By-the-mile	0.53	0.26, 1.07
By-the-load	1.03	0.40, 2.63
Miles per week (reference: 3,000 + miles)		
Less than 2,500 miles	0.53*	0.28, 1.00
2,500 – 2,999 miles	0.80	0.45, 1.42
Daily work hours (reference: 13 or more daily)		
Less than 11 h	0.19**	0.10, 0.36
Between 11 and 13 h	0.43**	0.24, 0.78
Fast pace of work (reference: higher frequency)	0.42**	0.24, 0.72
Supervisor support (reference: low support)	0.47	0.18, 1.19
Told supervisor too tired (reference: no)	1.28	0.77, 2.13
Worknight sleep duration	0.80**	0.67, 0.95
Worknight sleep quality (reference: almost always or always good)	0.66	0.39, 1.13
Note. χ = 80.86, p less than 0.01, Cox & Snell R^2 = 0.29, Nagelkerke R^2 = 0.31		

** p < 0.01; * p < 0.05

driver compensation away from by-the-mile pay structures and making pay fairer, and revisiting HOS policies may represent high-leverage targets for improving HOS compliance and reducing sleep-related safety risks.

4.1. Pace of work, hours-of-service violations, and sleep-related safety risk

Drivers' pace of work emerged as a significant predictor in the HOS compliance model. This corresponds with existing research that has shown that drivers' schedules can induce HOS violations (Beilock, 2003). However, it was surprising that it was not significant predictor of sleep-related safety risk, given the existing literature that has demonstrated the connections between pace-of-work and adverse safety outcomes. For example, drivers with fewer dispatches have lower likelihoods of crash involvement (Rodriguez, Targa, & Belzer, 2006). Further, pace of work constitutes a form of work pressure (Brodie, Lyndal, & Elias, 2009), and work pressures have been associated with crashes (Belzer, 2018). An increased pace of work can induce risky driver behaviors that correspond with increased crash risks, such as driving while fatigued and speeding (Belzer, 2018; Cantor, Corsi, Grimm, & Özpolat, 2010; Farrell et al., 2016; Federal Motor Carrier Safety Administration, 2018a). As the other significant predictors of HOS violations in the current study, greater worknight sleep duration, fewer daily work hours, and fewer miles per week predicted less frequent HOS violations. Other studies have similarly shown that decreased sleep

Table 4
Multinomial logistic regression model for Sleep-Related Safety Risk.

Sleep-Related Safety Risk (reference: 0 safety risk outcomes)	OR	*95% CI*
One safety risk outcome		
Compensation (reference: other)		
By-the-mile	0.96	0.35, 2.64
By-the-load	0.81	0.19, 3.44
Miles per week (reference: 3,000 + miles)		
Less than 2,500 miles	1.42	0.56, 3.61
2,500 – 2,999 miles	1.48	0.60, 3.63
Daily work hours (reference: 13 or more daily)		
Less than 11 h	0.37*	0.14, 0.98
Between 11 and 13 h	0.61	0.25, 1.50
Fast pace of work (reference: high frequency)	0.53	0.23, 1.18
Supervisor support (reference: low support)	0.21	0.04, 1.24
Told supervisor too tired (reference: no)	1.17	0.52, 2.64
Worknight sleep duration	0.97	0.75, 1.25
Worknight sleep quality (reference: never or rarely good)	1.18	0.51, 2.76
Work over 14 h daily (reference: at least sometimes)	1.14	0.44, 3.00
Work over 70 h weekly (reference: at least sometimes)	0.82	0.26, 2.56
Take fewer than 10 h rest (reference: at least sometimes)	2.14	0.82, 5.57
Underreport work hours (reference: at least sometimes)	1.67	0.55, 5.10
Two or more safety risk outcomes		
Compensation (reference: other)		
By-the mile	1.49	0.58, 3.79
By-the load	1.59	0.46, 5.48
Miles per week (reference: 3,000 + miles)		
Less than 2,500 miles	0.70	0.30, 1.62
2,500 – 2,999 miles	0.83	0.39, 1.78
Daily work hours (reference: 13 or more daily)		
Less than 11 h	0.44	0.18, 1.05
Between 11 and 13 h	0.49	0.21, 1.12
Fast pace of work (reference: high frequency)	0.52	0.25, 1.08
Supervisor support (reference: low support)	0.17*	0.03, 0.88
Told supervisor too tired (reference: no)	0.42*	0.22, 0.84
Worknight sleep duration	0.80	0.63, 1.01
Worknight sleep quality (reference: never or rarely good)	1.02	0.50, 2.10
Work over 14 h daily (reference: at least sometimes)	1.33	0.57, 3.10
Work over 70 h weekly (reference: at least sometimes	1.26	0.50, 3.15
Take fewer than 10 h rest (reference: at least sometimes)	1.37	0.61, 3.09
Underreport work hours (reference: at least sometimes)	0.54	0.22, 1.32

Note. χ = 52.45, p less than 0.01, Cox & Snell R^2 = 0.20, Nagelkerke R^2 = 0.23.
** $p < 0.01$; * $p < 0.05$.

duration (Hanowski, Hickman, Fumero, Olson, & Dingus, 2007; Hanowski, Wierwille, & Dingus, 2003; Pack et al., 2006) and increased work hours (Belzer, 2018; Blanco et al., 2011; C. Chen & Xie, 2014b; Gander, Marshall, James, & Le Quesne, 2006) and miles per week (Beilock, 2003; Rocha, 2003; Rodriguez et al., 2006) to be associated with an increased risk of crashes. It is likely that these variables also measure pace of work, as they speak to the workloads of drivers (daily work hours, miles per week) or other work pressure-related factors induced by pace of work that may degrade sleep duration (e.g., loss of sleep due to the stress of having to meet deadlines).

However, while miles per week and sleep duration were not significant predictors in the safety risk model, supervisor-related variables were significant. This may indicate that the quality of the driver-supervisor relationship is a key mediator in how workload spills over to impact safety outcomes. Supervisors (i.e., dispatchers) are typically the main point of contact for drivers and are responsible for freight assignments and on-time pickups and deliveries of freight; because of this, supervisors have profound influence on drivers' work schedule, and thereby their pace of work and work pressure (Farrell et al., 2016; Newnam et al., 2019). The current findings somewhat align with previous (related) studies that have shown that a distant leadership style and work ownership among dispatchers promote drivers' perception of safety climate; further, drivers' perception of safety climate and driver engagement have been shown to be predictors of safety behavior, while driver engagement moderated the effect of perceptions of safety climate on behaviors (Zohar, Huang, Lee, & Robertson, 2014; Zohar, Huang, Lee, & Robertson, 2015). Here, increased supervisor support was associated with reduced odds of experiencing sleep-related safety risks, which may reflect the drivers' perceptions of the safety climate; however, drivers who told their supervisors they were too tired to drive had greatly increased likelihoods of experiencing sleep-related safety risks, which may reflect drivers' degree of engagement and/or a less distant leadership style or reduced work ownership on the part of dispatchers. Because the driver-supervisor relationship appears to be critical in drivers' sleep-related safety risks, strengthening these relationships and improving supervisor leadership and risk management techniques may improve safety outcomes.

4.2. Compensation, hours-of-service violations, and sleep-related safety risk

Daily work hours and pace of work may be induced or exacerbated by extant pay structures in the trucking industry. By-the-mile pay is the prevailing compensation type in the long-haul trucking industry, where drivers are principally compensated based on mileage, which is typically based on the shortage distance to get from the city limit of the starting point to the city limit to the destination point ("What can practical miles do for you?," 2014). As a result, certain routes almost inevitably involve driving miles that are uncompensated. Further, drivers that are paid by-the-mile are not compensated for time spent performing other essential job tasks, such as pre- and post-trip inspections, maintenance, and paperwork, which are thought to make up 25% of their work time (Belzer, 2000). This issue is potentially compounded for LHTD, who are away from home for prolonged periods and essentially spend their off-duty time at work but are also not compensated for taking these mandatory off-duty breaks (Farrell et al., 2016).

Although the driver compensation variables were not significant predictors in either model, the patterns of odds ratios warrant discussion. Compared to the other compensation types, by-the-mile compensation surprisingly predicted less frequent HOS violations. A potential explanation for the former can be obtained from a study that found that drivers, on average, do not work or drive the maximum number of hours available to them per HOS regulations (Farrell et al., 2016). This effect may also be modified by the specific amount of compensation per mile drivers are receiving, as companies that pay at a higher rate may have a preference that their drivers comply with HOS regulations, while companies that pay at a lower rate may (directly or indirectly) encourage their drivers to violate these laws (Belzer & Sedo, 2018). Regarding the role of by-the-mile compensation as a predictor in the sleep-related safety risk model, although the lack of statistical significance was surprising, the increased odds of having two or more sleep-related safety risk outcomes compared to other compensation types was not, as these types of compensation have been associated with greater fatigue and increased crash risks in other studies (Belzer, 2018; Thompson & Stevenson, 2014; Williamson & Friswell, 2013). Additionally, drivers who are not paid for their nondriving time, such as those paid by-the-mile, have been found to work longer hours to compensate (Belzer & Sedo, 2018), and by-the-mile pay structures have been associated with longer daily and weekly work hours and higher distances traveled per day than other types of pay (Thompson & Stevenson, 2014). It should be noted that these findings need to be interpreted with caution, as over 70% of the drivers in this sample were paid by-the-mile, and thus the connections between compensation type, HOS compliance, and safety outcomes warrant further exploration. However, as evidenced here, making pay structures fairer for LHTD will likely have positive implications for safety outcomes

4.3. Hours-of-service violations and sleep-related safety risk

The three variables related to HOS violations – the 14-hour rule, the 70-hour rule, and the 10-hour rest breaks rule – did not emerge as significant predictors of sleep-related safety risk. This pattern of findings is counterintuitive in the context of several extant studies on the effects of HOS regulations on commercial driver roadway safety, which have found that: Crash and injury rates were reduced in aggregate following the implementation of the current HOS regulations (Dick et al., 2006); drivers' rates of out-of-service violations (e.g., exceeding the 11-hour, 14-hour, or 70-hour rules) were predictors of future crash involvement (Cantor et al., 2010); longer driving times are associated with higher likelihoods of roadway crashes, and reduced driving time limits reduce crash risks (Gander et al., 2006; Goel, 2014; Hall & Mukherjee, 2008); and 10-hour rest breaks reduce roadway crash risks (Blanco et al., 2011; Garbarino et al., 2016). However, other studies have suggested that prolonged driving was not a significant predictor of having a roadway crash (Häkkänen & Summala, 2001), and that extended off-duty times or 34-hour restart periods do not effectively reduce crash risk and may increase crash risks (Blanco et al., 2016; C. Chen & Xie, 2014a; Jovanis, Wu, & Chen, 2011). It has also been suggested that the safety improvements observed following the implementation of the latest HOS regulations are not due to those regulations, but rather to other changes that have taken place during that same time period (Anderson et al., 2017).

One possible way to interpret the findings in the current study is that the safety risks encountered by those drivers who violate HOS statutes may be counterbalanced because they are doing so as a means to exert job control that leads to positive safety consequences. For example, the flexibility afforded by driving extra hours and violating the 14-hour rule or 70-hour rule, or by cutting rest breaks short and violating the 10-hour rest breaks rule, may allow drivers the safety benefits of sleeping during nighttime hours and thereby staying off the road during these high-risk driving times (Blower & Campbell, 1998; G. X. Chen, Fang, Guo, & Hanowski, 2016); avoiding high-risk traffic densities, such as by driving through major metropolitan areas during non-peak traffic hours (Hanowski, Hickman, Olson, & Bocanegra, 2009); or reaching safer and more quiet rest locations that allow for improved sleep duration and quality. Given the findings of the current study in the context of the existing literature, along with broader trends in roadway safety outcomes among commercial drivers, policymakers should consider revisiting HOS regulations in the context of both their safety benefits (e.g., limiting the number of work hours among LHTD) and also the costs of the current design of the regulations (e.g., how they limit the flexibility of LHTD in making trip planning decisions that may mitigate crash risks).

4.4. Limitations

There are a few limitations of this study. First, while the sample size of this study was sufficient for identifying several important relationships of interest, a larger sample size would have increased the statistical power of the analyses. Second, because our data were self-reported measures, various subjective biases inherent to self-report measures may be present in our findings, such as those related to the potential tendency of LHTD to underreport legal violations. Next, as is the case with all cross-sectional research, it is impossible to ascertain temporality among variables, and therefore any potential cause-effect relationships must be interpreted with caution. Finally, due to the mobility of the long-haul truck driving profession, data in this study were collected from drivers who operate out of aa wide array of states across the U.S. However, these data were collected at only one truck stop; therefore, it is possible that selection and sampling biases may be present in our findings.

5. Conclusions

Long-haul truck drivers experience the most work-related fatalities of any occupation, and number of these trucks involved in fatal, injury, and property damage crashes have all risen in recent years. Hours-of-service regulations constitute key public policies aimed at improving safety outcomes, but these laws continue to engender controversy among industry stakeholders and policymakers. Greater miles per week, longer daily work hours, a more frequent fast pace of work, and shorter worknight sleep duration were significant predictors of increased frequency of HOS violations. Longer daily work hours, lower levels of supervisor support, and failing to tell a supervisor about being too tired to drive were significant predictors of experiencing sleep-related safety risks, while none of the HOS compliance variables emerged as significant predictors of these undesirable outcomes. In light of these findings, reducing daily work hours and pace of work, strengthening driver-supervisor relationships and improving supervisor leadership and risk management techniques, making driver compensation fairer, and revisiting HOS policies may represent high-leverage targets for improving regulatory compliance and safety outcomes.

CRediT authorship contribution statement

Michael K. Lemke: Formal analysis, Writing - original draft, Writing - review & editing. **Adam Hege:** Formal analysis, Writing - original draft, Writing - review & editing. **Yorghos Apostolopoulos:** Writing - review & editing. **Sevil Sönmez:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to thank Mr. Tom Liutkus, Vice President of Marketing and Public Relations for Travel Centers of America (TA) and Mr. Jerald Brisson, General Manager of the Whitsett, NC TA truckstop and his staff for their instrumental support for our project and data collection efforts. We also thank the long-haul truck drivers who participated in this study and extend our thanks to our graduate student Kiki Hatzudis for her invaluable assistance in various phases of data collection.

Funding

This paper is part of a commercial driver sleep study conducted with research funds awarded by the University of North Carolina-Greensboro's (UNCG) Office of Research and Economic Development. Additional funds were provided by UNCG's School of Health and Human Sciences, Bryan School of Business and Economics, Department of Public Health Education, and Department of Kinesiology.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2020.11.017.

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